Dr Couch

Journal

OF THE

ELISHA MITCHELL Scientific Society

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Contents

PROCEEDINGS OF THE FIFTY-SECOND ANNUAL MEETING OF THE NORTH CAROLINA ACADEMY OF SCIENCE 157

PROCEEDINGS OF THE ELISHA MITCHELL SCIENTIFIC SOCIETY 180

PROOF OF THE SUM AND DIFFERENCE FORMULAS IN TRIGONOMETRY *T. F. Hickerson* 181

CONTINUOUS PRODUCTS IN LINEAR SPACES ..... *J. S. MacNerney* 185

A SURVEY OF NORTH CAROLINA SHRIMP NURSERY GROUNDS *Austin B. Williams* 200

LOCAL VARIATION AND RELATIONSHIPS OF THE CYPRINODONT FISH, FUNDULUS RATHBUNI JORDAN AND MEEK ..... *Jerram L. Brown* 207

ANOTHER MYCOTYPHA ..... *Frederick A. Wolf* 213

NORTH AMERICAN LEJEUNEACEAE. III. PARADOXAE: COLOLEJEUNEA, SECTIO MINUTISSIMAE ..... *Rudolf M. Schuster* 218

MICROMYCES GRANDIS, A NEW MEMBER OF THE AQUATIC SYNCHYTRIACEAE *Charles E. Miller* 247

DISTRIBUTION AND SPECIATION OF THE GENUS LUDWIGIA IN NORTH CAROLINA *James Alan Duke* 255

ACTINOSPORANGIACEAE SHOULD BE ACTINOPLANACEAE ..... *John N. Couch* 269

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The Elisha Mitchell Scientific Society

Founded in 1883 through the efforts of Francis Preston Venable

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JOURNAL

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PROCEEDINGS OF THE FIFTY-SECOND ANNUAL MEETING OF THE NORTH CAROLINA ACADEMY OF SCIENCE

The fifty-second annual meeting of the North Carolina Academy of Science was held at Davidson College, Davidson on May 6 and 7, 1955.

The Academy met in its first session at 10:30 a.m. on May 6 with President W. O. Puckett presiding. A symposium on Science in Industry in North Carolina was presented at this session.

The business meeting of the Academy was held at 4:30 p.m. at which the following business was transacted:

The minutes of the 1954 meeting were approved as published in the Journal of the Elisha Mitchell Scientific Society **70:** 105–134.

Report of the Executive Committee

The Executive Committee met at Davidson College Union on May 5 at 8:00 p.m. At this meeting the following matters were considered:

1. The Committee voted to continue the Academy support for the Collegiate Academy, to underwrite its promotional expense, and to supply two awards, $25 and $15, except as these may be furnished by special donors. It noted with thanks that the Carolina Biological Supply Company this year donated the first prize of $25. Dr. Charlotte Dawley was asked to continue in her rôle as sponsor, although her request for the naming of an associate sponsor was granted by the Committee.
2. The Secretary reported the following facts about membership:

1. Loss by resignation and non-payment of dues	96
2. Gain—new members and reinstatements (1954–55)	101
3. Total membership (revised, as of July 1, 1955)	506

3. The following were elected to membership in the Academy or reinstated to active membership:

Allison, Dr. Joseph L., N. C. State College, Raleigh
Barton, Jack S., Greensboro
Bass, Joe N., Bessemer City
Becker, David A., N. C. State College, Raleigh
Brinkley, H. M., Jr., Liggett and Myers, Durham
Brinson, Mrs. Martha G., Kenansville
Brock, Brantley A., Liggett and Myers, Durham
Brown, Henry S., Marion
Brun, Dr. Wm. A., N. C. State College, Raleigh
Carpenter, Dr. Irvin W., Jr., Appalachian State College, Boone

Carriker, Dr. Melbourne R., University of N. C., Chapel Hill
Christy, Melvin G., Liggett and Myers, Durham
Cramer, Dr. Robert E., East Carolina College, Greenville
Crawford, Dr. George W., Davidson College, Davidson
Crowder, Wilbur S., Liggett and Myers, Durham
Davis, James M., Jr., Wadesboro
Delamar, Carl D., Liggett and Myers, Durham
Derrick, F. Ray, Appalachian State Teachers College, Boone
Derrick, John C., Liggett and Myers, Durham
Dockery, Jack D., Western Carolina College, Cullowhee
Dogger, Dr. James R., N. C. State College, Raleigh
Duhling, William H., Jr., N. C. State College, Raleigh
Eller, J. G., Western Carolina College, Cullowhee
Elliott, Greer W., Liggett and Myers, Durham
Fairey, Robert L., Liggett and Myers, Durham
Fisher, Dr. T. Richard, Appalachian State Teachers College, Boone
Fisher, William D., Duke University, Durham
Forrister, Charles L., Western Carolina College, Cullowhee
Freeman, Miss Claire, Raleigh
Freeman, Mrs. Mary W., Fayetteville
Fresh, James W., N. C. Memorial Hospital, Chapel Hill
Garren, Dr. Henry W., N. C. State College, Raleigh
Garriss, Howard R., N. C. State College, Raleigh
Gerritsen, Burton A., Liggett and Myers, Durham
Gilmore, Mrs. Christine R., Candler
Gray, Mrs. Mary C., Lenoir-Rhyne College, Hickory
Guthrie, Dr. Frank E., N. C. State College, Raleigh
Halliburton, Mrs. Hilda S., Clyde
Hassler, Dr. William W., N. C. State College, Raleigh
Herbst, Dr. Robert T., Office of Ordnance Research, Durham
High, Miss Alease, Roanoke Rapids
Hodges, F. A., Western Carolina College, Cullowhee
Hollowell, Mrs. Claudia B., Goldsboro
Jacobs, Dr. Merle E., Duke University, Durham
Jenkins, Miss Eleanor L., Queens College, Charlotte
Johnson, Dr. Terry W., Jr., Duke University, Durham
Keith, Dr. Charles H., Liggett and Myers, Durham
Little, Miss Margaret C., St. Pauls
Lofquist, George W., Warren Wilson College, Swannanoa
Lowry, Dr. Edward M., Meredith College, Raleigh
Matrone, Dr. Gennard, N. C. State College, Raleigh
McElvare, Rowland R., Southern Pines
McLeod, Mrs. Rachel B., Cary
McRae, Marshall T., Liggett and Myers, Durham
Means, Richard E., Liggett and Myers, Durham
Menius, Dr. A. C., Jr., N. C. State College, Raleigh
Mold, Dr. James D., Liggett and Myers, Durham
Moser, Miss Ruth F., Charlotte
Murray, Dr. Raymond L., N. C. State College, Raleigh
Nease, Dr. F. R., Durham
Nelson, Rolla C., Raleigh
Newell, E. B., Catawba College, Salisbury
Newsome, John R., Liggett and Myers, Durham
Nicholson, John, Salisbury
Odum, Dr. Howard T., Duke University, Durham

Orlohundro, Warren W., Greensboro
Parker, William A., Catawba College, Salisbury
Parrish, Dr. Henry M., Bowman-Gray Medical School, Winston-Salem
Phifer, Sam E., N. C. State College, Raleigh
Pietenpol, Dr. C. J., Davidson College, Davidson
Porter, Hugh J., Institute of Fisheries Research, Morehead City
Rabb, Dr. Robert L., N. C. State College, Raleigh
Ray, Bobby G., Sugar Grove
Reichle, Col. Paul A., Lenoir-Rhyne College, Hickory
Roe, Dr. Arthur, University of N. C., Chapel Hill
Rogers, James D., Liggett and Myers, Durham
Samfield, Dr. Max, Liggett and Myers, Durham
Schramm, Robert J., Jr., N. C. State College, Raleigh
Schulz, Henry L., Liggett and Myers, Durham
Shearin, Dr. Paul E., University of N. C., Chapel Hill
Shuster, C. Willard, Duke University, Durham
Simmons, Dr. Raymond O., N. C. State College, Raleigh
Skotland, Dr. C. B., N. C. State College, Raleigh
Smith, Dr. Kendon, W. C. U. N. C., Greensboro
Smith, Richard C., Duke University, Durham
Stallard, Frank W., University of N. C., Chapel Hill
Sunas, Ernest C., Liggett and Myers, Durham
Sutton, Rufus R., U. S. Army Medical Dept., LaGrange
Turlington, Miss Helen, Greensboro College, Greensboro
Turner, Dr. Thomas J., Wake Forest College, Wake Forest
Turner, Dr. W. Newton, Western Carolina College, Cullowhee
Underwood, Dr. Newton, N. C. State College, Raleigh
Veasey, Lee G., Jr., Liggett and Myers, Durham
Walker, Dr. Lila P., W. C. U. N. C., Greensboro
Weaver, James B., Jr., N. C. State College, Raleigh
Weidlich, William R., Liggett and Myers, Durham
Williams, Dr. John F., Liggett and Myers, Durham
Willis, Mrs. Margaret C., New Bern
Winstead, Dr. Nash N., N. C. State College, Raleigh
Yow, Francis W., Western Carolina College, Cullowhee
Zener, Dr. Karl, Duke University, Durham

4. The Committee recommended Life Membership in the Academy for Dr. B. B. Fulton, Professor of Zoology, North Carolina State College, Dr. Frederick A. Wolf, Professor of Botany, Duke University and past president of the Academy, Miss Elva E. Barrow, Professor of Chemistry, Woman's College, U.N.C., and Dr. Thomas F. Hickerson, Professor of Mathematics, U.N.C.
5. It discussed the organization of a section of Chemistry within the Academy and appointed Dr. C. S. Black and the incoming president of the Academy (Dr. E. C. Cocke) as a special committee to explore further into this possibility for next year.
6. The Committee accepted with pleasure the invitation of the University of North Carolina to have the Academy meet in Chapel Hill in 1956. The new Executive Committee was instructed to study the possibility of arranging for a date earlier in the spring than the traditional early May date.

The above reports and actions of the Committee were approved by the Academy in its business session on May 6, 1955.

TREASURER'S REPORT

Financial Statement as of July 1, 1955

Receipts		
Checking account balance (Security National Bank, Raleigh) from August 1, 1954		$ 50.32
Transfer from Savings Account (Security National Bank)		100.00
Special income		
Ornithology essay awards (District and State)		141.00
Wildlife essay awards (District)		60.00
Physical Science State Fair Awards		100.00
N. C. Psychological Association		6.00
N. C. Section, American Chemical Society		75.00
Central N. C. Section, American Chemical Society		25.00
Eastern N. C. Section, American Chemical Society		25.00
Collegiate Award Fund (Dr. S. W. Hoffman)		25.00
Gifts from members for High School Science Fairs		131.66
Collegiate Academy Fund Deposit		39.00
Dues from membership, 1955 (1954 and 1956)		1469.50
Total		2247.48
Expenditures		
Ornithology Essay Awards (District and State)		150.00
Wildlife Essay Awards (District)		60.00
Physical Science, State Fair Awards		100.00
Collegiate Academy, Second place Award		15.00
Entry Fee for National Science Fair		150.00
Postage, Stationery, Supplies for office		237.17
Expenses of annual meeting, 1955		10.64
Expenses of High School Fair Committee		31.58
Printing of brochure for science fairs		168.65
Printing, all other		159.25
Bank charges		2.66
Secretarial aid		61.50
Secretary's commission (balance on 1953–54)		20.58
Secretary's commission (1954–55)		145.00
Telephone (long distance calls)		34.22
Collegiate Academy expense		19.64
Reprints of 1954 Proceedings of Academy		17.55
Elisha Mitchell Scientific Society		553.00
Total		1936.44
Bank balance, July 1, 1955	$396.01	
Less outstanding checks	84.97	
Adjusted balance	311.04	311.04
		2247.48

Savings Account

Balance from August 1, 1954	$108.24
Interest	0.54
Total	108.78

Withdrawals	100.00
Balance, July, 1955	8.78

Total Assets

Checking account	$311.04
Savings account	8.78
Raleigh Building and Loan Company	308.31
Total	$628.13

On the 14th day of July, 1955, we, the undersigned, examined this account and found it to be correct.

(Signed) L. A. WHITFORD
SAM D. BROADHURST
KEY L. BARKLEY, *Chairman*

THE POTEAT AWARD

The award for this year was given to the best paper presented before the combined Mathematics-Physics Section. The selection was made by members attending the section meeting of this group where papers were presented. The winner of this year is Raymond L. Murray of North Carolina State College for his paper, "The physics of nuclear reactors."

CONSERVATION AND LEGISLATIVE COMMITTEE

No formal report was given by this committee at the 1955 meeting, although one meeting of the group was reported for the Academy year.

ACADEMY CONFERENCE AND AAAS COUNCIL

No representative was sent from the Academy to the 1954 meetings held in Berkeley, California; thus no report was given at this Academy meeting.

REPORT ON THE COLLEGIATE ACADEMY

A meeting of the executive committee of the Collegiate Academy was called in October by Dr. Yarbrough. The officers elected last May were present: President, Joe Rowland, East Carolina College; Vice-President, Edith McCauley, Elon College; Secretary-Editor, William Owens, Atlantic Christian College. Other interested persons, both faculty and student, were invited. A general discussion of the basis for membership, amount of dues, activities, and future meetings was held, and after this meeting, the organization was turned over to me as faculty sponsor. I was also to serve as treasurer.

In January, William Owens, the editor, prepared and mailed out the first edition of CANCAS (Collegiate Academy, North Carolina Academy of Science). This four-page mimeographed sheet was sent to all four-year colleges, white and colored, in North Carolina, to be distributed to all science majors. On the last page was a call for members and an application blank, to be accompanied by $1.00 dues.

In March, I sent out a call for papers, the titles to be sent in by April 15.

Seven were received and appear on the printed program. Two more were received too late to be printed.

At present we have 24 paid-up members (16 others joined at the Davidson meeting). Atlantic Christian College, Catawba College, and Greensboro College, as well as the seven colleges mentioned in the printed program are represented in this group.

I would like to recommend that at least two faculty members be appointed as sponsors, one to work with the editor on any bulletins that may be sent out, and the other to be the treasurer and to organize the May meeting.

CHARLOTTE DAWLEY, *Sponsor*

At the session of the Collegiate Academy on May 6 Miss Ossie Marie Brewer of Guilford College won the first place award with her paper, "Study of the effect of *Salmonella typhimurium* on the acquired resistance of mice to *Trichinella spiralis*" and Mr. Scott W. Chilton of Duke University won the second place award with his paper, "Preparation and microbiological properties of 5-(1-alkyl ethylidene) 2,4-dioxothiazolidines." Honorable mention was given by a panel of judges to Mr. James G. McNally, Jr. of Duke University and Mr. James T. Bowman of Duke University for their excellent papers in the Collegiate Academy. In its business session the Collegiate Academy elected the following officers to serve during 1955–56: President, Charles Childs, U.N.C., Vice-President, William Owens, A.C.C. and Secretary-Editor, Margaret Hollands, W.C.U.N.C.

REPORT OF THE RESOLUTIONS COMMITTEE

Be it resolved that the North Carolina Academy of Science express to President J. R. Cunningham, the other administrative officers, the faculty, and the students of Davidson College its appreciation and thanks for their gracious hospitality and for the many services that have contributed to the success of the Academy's fifty-second meeting; also that the Academy express its thanks to the members of the Local Committee on Arrangements for their careful planning for this meeting. Be it further resolved that a copy of this resolution be incorporated into the minutes of the Academy and that copies be sent to President Cunningham and to the chairman of the Committee on Arrangements.

EVA G. CAMPBELL

The above resolution was unanimously approved by the Academy.

A memorial to Edgar Eugene Randolph was read before the Academy by G. H. Satterfield. This memorial was approved by a rising vote of those present.

EDGAR EUGENE RANDOLPH

Edgar Eugene Randolph, Professor Emeritus of Chemical Engineering at North Carolina State College, died at his home in Raleigh on November 10, 1954.

Dr. Randolph was born in Mecklenburg County, North Carolina, July 22, 1878. He was educated at Sardis Academy and the University of North Carolina where he won his A.B., A.M. and Ph.D. degrees. He later did graduate work in

Chemical Engineering at the Massachusetts Institute of Technology and for one year was a Carnegie Research Assistant, working at the College of the City of New York.

Dr. Randolph held professorships at Lenoir-Rhyne College, Elon College, A. and M. College of Texas, and North Carolina State College, to which he came in 1920. He taught several summers at Appalachian State Normal College and Tulane University. In 1924 the Board of Trustees authorized a Department of Chemical Engineering at North Carolina State College. Dr. Randolph was appointed its head and it was from this position that he retired in 1946. Following his retirement he remained active as a consulting chemical engineer.

During his active career he had plant experience with the Revere Sugar Refinery and with the Bethlehem Steel Company. He served as a consulting chemical engineer at various times for the Carolina Power and Light Company and the Southern Public Utility Company on gas plant problems; for the State Budget Bureau on the quality and specifications of fuels for State Institutions; for the State Department of Conservation and Development on the quality of surface waters for industrial uses, and for the Utilities Commission on gas plant inspections. He was a ranger during one summer in Yellowstone National Park.

He was for many years a faithful and active member of the Academy. He was a member of the American Chemical Society, the American Society for Engineering Education, American Society for Testing Materials, and the American Institute of Chemical Engineers. In 1936 he organized the North Carolina Water Works Association and in 1938 the North Carolina School for Gas Workers which subsequently became the Southeastern Gas Association. He was also a member of the North Carolina Society of Engineers, Raleigh Engineers Club and of the honor societies Tau Beta Pi and Phi Kappa Phi.

Dr. Randolph published two books and a number of articles in technical and scientific journals. He had a keen interest in the utilization and development of North Carolina resources. His fields of research included such problems as water quality and water conditioning, industrial wastes, wood products, fish oil industries, farm product utilization and industrial corrosion.

In addition to being a recognized leader in the field of education and research, Dr. Randolph maintained a keen interest in the welfare of his students. He knew every student in his department and something of his background. He was above all interested in human values and was never too busy to discuss a student's problem with him. During depression years, he worked many long hours toward securing employment for his and other State College graduates.

Dr. Randolph had little with which to build his department. Financial aid for equipment and supplies was meager. However, his many contacts plus a determination to succeed enabled him to get together the equipment necessary for his laboratories. Despite these handicaps his approximately 600 graduates have been able to compete on equal terms with chemical engineers from other schools throughout the country.

He married Ora M. Huffman on December 30, 1909. Mrs. Randolph shared with her husband a continuing interest in the affairs of both the department and

its students and her assistance and understanding became significant factors in his success.

In his death the University, the Academy and the State of North Carolina have lost a most distinguished and loyal member.

J. F. SEELY
R. BRIGHT

SCIENCE EDUCATION IN THE HIGH SCHOOLS

Departing from its custom of sponsoring two essay contests and a science exhibit contest at the Academy meeting, the Academy during the past year has sponsored a much enlarged program designed to promote science education in the high schools. This program consisted of three main parts:

1. Essay contests in forestry, ornithology and wildlife with both district and statewide competition.
2. Six district science fairs and a State science fair for the exhibit of individual science projects in the biological and in the physical sciences.
3. A North Carolina Science Talent Search conducted in co-operation with the national Westinghouse Talent Search.

The essay contests and the science fairs were conducted by the High School Committee of the Academy with Dr. Hollis J. Rogers as chairman. Other leaders in this work were Dr. Thomas D. Reynolds, chairman of the State science fair held at Duke University on April 22 and 23 with that institution as host, and the district fair chairmen as follows: Dr. J. O. Derrick, Northeastern District; Dr. Alfred F. Borg, North Central District; Dr. Amy LeVesconte, Southeastern District; Dr. Robert J. Laffin, Northwestern District; Hansel L. Hughes, South Piedmont District; J. G. Eller, Western District. Colleges serving as hosts for the district fairs were East Carolina College, North Carolina State College, Flora Macdonald College, Woman's College, U.N.C., Catawba College, and Western Carolina College.

The committee for the first North Carolina Science Talent Search consisted of Dr. B. B. Brandt as chairman, Dr. J. M. Clarkson and Henry A. Shannon.

Numerous local science fairs, though not directed by the Academy, were apparently stimulated by the program of district and state fairs sponsored by the Academy. Two students, winning highest honors in the State fair, were sponsored in their trip to the National Science Fair held in Cleveland, Ohio, May 12–14. The Academy provided the entrance fee for the national trip winners and their respective home communities provided travel expense. These winners were Leonidas Betts, Fuquay Springs High School, Fuquay Springs and Charles Canada, Guilford High School, Guilford. Both of these students won awards in the National Fair for being in the upper 25% of the competition there. As second place winners in the State science fair, William Montgomery, Myers Park Junior High School, Charlotte and Charles Egerton, Durham High School, Durham were given honorary memberships in the AAAS for one year. These are offered through the courtesy of the AAAS.

Three winners in the North Carolina Science Talent Search were chosen: M. H. Vaughn, Jr., New Hanover High School, Wilmington; Lawrence L. Lohr, Jr., Needham Broughton High School, Raleigh; Samuel J. Johnson, Elizabeth City High School, Elizabeth City. Vaughn had previously been placed in the upper forty students in the entire country in the national Westinghouse Search and was given an all-expense trip to Washington, D. C. in February to enter the competition there. Robert T. Kirkland, Jr., Needham Broughton High School, Raleigh, was named an honorable mention in the State Talent Search.

Winners in the State contests in essay writing were:

Forestry Essay Contest

(Sponsored by the North Carolina Forestry Association)

"Living with Wood—Contributions of Trees and Forest Products to Everyday Living"

First Prize: Dianne Stokes, Kenansville High School, Kenansville
Second Prize: Jim Cooper, Boyden High School, Salisbury
Third Prize: Betty Jean King, Calypso High School, Mt. Olive

Ornithology Essay Contest

"The Migrations of Birds"

First Prize: David Cooper, Cary High School, Cary
(Sponsored by Mrs. E. O. Clarkson)
Second Prize: Linda West, Contentnea High School, Kinston
(Sponsored by Representative Thurmond Chatham)
Third Prize: Betty Lou Holland, Calypso High School, Mt. Olive
(Sponsored by Dr. and Mrs. W. C. Mebane)

Wildlife Essay Contest

"The Economic Value of Wildlife in My Community"

(Sponsored by the North Carolina Wildlife Federation)

First Prize: Jean Owens, Lumberton High School, Lumberton
Second Prize: Saundra Cordell, Candler High School, Candler
Third Prize: Mayme Roberson, Candler High School, Candler

STATE SCIENCE FAIR WINNERS

Biological Science

(Sponsored by the Carolina Biological Supply Company)

First Prize: Leonidas Betts, Fuquay Springs High School, Fuquay Springs
Second Prize: Charles Egerton, Durham High School, Durham
Honorable Mention: Betty Lou Wallace, Mt. Park High School, Mt. Park; Peggy Lennon, Greensboro Senior High School, Greensboro; Robert L Smith, Albemarle High School, Albemarle

Physical Science

(Sponsored by Cardinal Products, Inc.)

First Prize: Charles Canada, Guilford High School, Guilford
Second Prize: William Montgomery, Myers Park Junior High School, Charlotte
Third Prize: Harriet Suzanne Cameron, Hoke County High School, Raeford

Mention should be made in this report of the numerous special gifts of money made during the past year to the High School Science program. More than thirty members of the Academy made special gifts for this purpose. Special gifts were also made by the North Carolina Section of the American Chemical Society, the Central North Carolina Section of the American Chemical Society and the Eastern North Carolina Section of the American Chemical Society.

REPORT OF THE NOMINATING COMMITTEE

The committee, consisting of H. R. Totten, chairman, B. W. Wells and F. A. Wolf, submitted the following nominations:
President: E. C. Cocke, Wake Forest College
Vice-President: Henry W. Jensen, Warren Wilson College
Secretary-Treasurer (for three year term): John A. Yarbrough, Meredith College
Member of the Executive Committee: L. A. Whitford, N.C. State College
Member of the Research Grants Committee: H. J. Oosting, Duke University

The above nominees were unanimously elected by the Academy. This concluded the business and the meeting was adjourned.

Approximately 125 members of the Academy, guests, and friends enjoyed the Annual Dinner of the Academy which was held in the Ballroom of the Davidson College Union at 7 p.m. Vice-President A. D. Shaftesbury presided over the evening session of the Academy which followed the banquet in the same room. The 1954 Poteat Award was presented *in absentia* to Maurice C. Powers, formerly of the University of North Carolina, now at Bucknell University, Lewisburg, Pa. Dr. Powers' paper had been given in the Geology Section and was titled, "Clay mineralogical profile from fresh to salt water." A feature of the session was the recognition of three winners and one honorable mention in the first North Carolina State Science Talent Search conducted by the Academy in 1954–55 through the national Westinghouse Science Talent Search. Two representatives of the Westinghouse Meter Plant in Raleigh were present and presented the four high school seniors as honor guests of the Academy. They were also presented beautiful Westinghouse clock-radios by the Westinghouse representatives. Winners in the first N.C. State Talent Search are M. H. Vaughn, Jr., New Hanover High School, Wilmington (also one of the forty national winners in the nation-wide Westinghouse Contest), Lawrence L. Lohr, Jr., Needham Broughton High School, Raleigh, and Samuel J. Johnson, Elizabeth City High School, Elizabeth City. Honorable mention went to Robert T. Kirland, Jr., Needham Broughton High School, Raleigh. Teachers of these outstanding high school students were also introduced as honor guests. They are Mr. Hayward Bellamy, New Hanover High School, Wilmington; Mr. Rolla C. Nelson, Needham Broughton High

School, Raleigh; Mrs. Norman T. Hodul, Elizabeth City High School, Elizabeth City; and Miss Claire Freeman, Needham Broughton High School, Raleigh.

In the annual presidential address, President W. O. Puckett presented a very interesting and informative discussion of "The Regeneration Problem."

Following the evening session all members and guests enjoyed a delightful social hour at the Davidson College Guest House.

The following officers were elected for the respective sections:

Biochemistry and Physiology: Chairman, G. Matrone; Secretary, James Fresh
Botany: Chairman, Victor A. Greulach; Secretary, B. W. Smith
Geology: Chairman, P. M. Brown; Secretary, E. W. Berry
Mathematics: Chairman, J. W. Lasley, Secretary, Gene Medlin
Physics: Chairman, Paul E. Shearin; Secretary, R. M. Helms
Zoology: Chairman, F. S. Barkalow; Secretary, Walter M. Kulash

The following constitute the personnel of the standing committees:

Executive: E. C. Cocke, Henry W. Jensen, John A. Yarbrough, E. W. Berry, C. S. Black and L. A. Whitford
Research Grants: H. E. LeGrand, O. J. Thies, Maurice Whittinghill, and H. J. Oosting

Dr. E. C. Cocke, President of the Academy for 1956, announced the appointment of the following committees:

Auditing: Key L. Barkeley, chairman; Sam D. Broadhurst, Arthur Kelman
Nominating: W. O. Puckett, chairman; J. L. Stuckey, Otto Stuhlman
High School Science Education: Hollis J. Rogers, chairman; Mazel B. Lyke, Henry A. Shannon, J. O. Derrick and R. C. Hatley
Conservation-Legislative: F. S. Barkalow, chairman; T. E. Maki, Dr. Wanda Hunter, C. T. Phillips and Harry LeGrand
Resolutions: L. A. Whitford
Derieux Memorial Award: Thomas J. Turner, chairman; Paul H. Cheek and R. M. Helms
North Carolina Science Talent Search: B. B. Brandt, chairman; J. M. Clarkson and Henry A. Shannon
Representative on A.A.A.S. Council: John A. Yarbrough
Representatives to Academy Conference: E. C. Cocke and John A. Yarbrough

The following papers were presented during the meetings. Those marked with an x are abstracted in these proceedings:

Presidential Address: The Regeneration Problem. W. O. Puckett, Davidson College

SYMPOSIUM ON SCIENCE IN INDUSTRY IN NORTH CAROLINA

Experience with the use of hydrazine as an oxygen scavenger in high pressure boilers. D. E. Voyles, Duke Power Company
Some practical applications of chemistry in the tobacco industry. Dr. William W. Bates, Liggett & Myers Tobacco Company

Development of the modern textile fiber. Dr. Howard J. Phillip, Celanese Corporation of America

COLLEGIATE ACADEMY

Chemical utilization of wood. Miriam Barrow, Flora Macdonald College

Distribution of the wood thrush and the veery in the Black Mountains, North Carolina. Fairman P. Cumming, Davidson College

Preparation and microbiological properties of 5-(1-alkyl ethylidene) 2,4-dioxothiazolidines. Scott W. Chilton, Duke University

Preparation and microbiological properties of some 5-alkyl rhodanine derivatives. James G. McNally, Jr., Duke University

The effect of distilled water on the survival of Serratia marcescens. Mary Forrest, Woman's College, U.N.C.

x*Study of the effect of Salmonella typhimurium on the acquired resistance of mice to Trichinella spiralis.* Ossie Marie Brewer, Guilford College

Amphibians of Alamance and Guilford counties, North Carolina. Jerry D. Hardy, Jr., Elon College

Some properties of central North Carolina lakes. James T. Bowman, Duke University

Informal discussion on opportunities for graduate work in science, led by Dr. Victor M. Cutter, Jr., of Woman's College, U.N.C.

BIOCHEMISTRY AND PHYSIOLOGY SECTION

Effects of unsaturated fatty acids and ultraviolet light on ascites tumor metabolism. C. Willard Shuster, Duke

The effect of genistin, as estrogen-like substance isolated from soybeans, on growth of the mouse. W. W. G. Smart, Jr., V. W. Smart, M. W. Carter, G. Matrone, and H. W. Garren, N.C. State

x*A test of specific uptake from organ homogenates by homologous organs in the young mouse.* Edward C. Horn and Mary Elizabeth House, Oak Ridge National Laboratory and Duke

Radioisotopes as tracers in cigarette smoke. William A. Wolff, Bowman Gray School of Medicine

Cholesterol levels in human cerumen. D. K. Owens and G. Howard Satterfield, N.C. State

Effect of high levels of manganese on hemoglobin formation. B. H. Hartman, Gennard Matrone, and G. H. Wise, N.C. State

Effect of some inhibitors on non-oxidative exchange of phosphate in mitochondria. Marjorie Swanson, Bowman Gray School of Medicine

Endocrine and lymphatic gland changes occurring in young chickens with fowl typhoid. Henry W. Garren, N.C. State

The effect of high levels of vitamins on the resistance of chicks to fowl typhoid. C. H. Hill and H. W. Garren, N.C. State

Sequence of formation of fatty acids in developing soybean seed. R. O. Simmons, N.C. State

x*A technique for measuring prothrombin.* James W. Fresh, U.N.C.

BOTANY SECTION

The use of closed circuit television for laboratory instruction in biology. Victor M. Cutter, Jr., Woman's College, U.N.C.

x*Pyrimidines as antagonists of maleic hydrazide.* Victor A. Greulach, U.N.C.

x*Internal structure of the swimming cell of some aquatic fungi.* William J. Koch, U.N.C.

x*Endosperm development in interspecific crosses in Gossypium.* James B. Weaver, Jr., N.C. State

x*False broom rape of tobacco in North Carolina.* Arthur Kelman, G. B. Lucas and H. R. Garriss, N.C. State

x*Puccinia graminis infection on Berberis in North Carolina.* Albert F. Thiel, Woman's College, U.N.C.

A brown alga new to the West Atlantic. H. L. Blomquist, Duke

Noteworthy plants from Polk County, North Carolina. Oliver M. Freeman, U.S.D.A.

x*Causes of remarkable variations in Strophostyles flowers.* A. L. Pickens, Queens College

x*Variation in the genus Heliopsis (Compositae).* T. Richard Fisher, Appalachian

x*The influence of water uptake on absorption of phosphorus by corn plants.* Richard C. Smith, Duke

GEOLOGY SECTION

x*Geology of Granville County, North Carolina.* Richard J. Councill, N.C. Department of Conservation and Development

x*Mineralogy of the Durham Triassic Basin, Northern Wake County.* W. H. Duhling, Jr., N.C. State

x*Petrography of the Sampson County, North Carolina, Pleistocene formations.* C. Edward Howard, N.C. State

x*The determination of radioactive opaque minerals in black sands.* Warren G. Steel, N.C. State

x*Gold deposits of Union County, North Carolina,* Sam E. Phifer, N.C. State

PHYSICS AND MATHEMATICS SECTION

Proof of "Sine and cosine sum and difference formulas." T. F. Hickerson, U.N.C.

Differential systems with interface conditions. F. W. Stallard, Oak Ridge Institute of Nuclear Studies

x*The physics of nuclear reactors.* Raymond L. Murray, N.C. State

Photographic localization of isotopes in lung tissue. E. G. Purdom and W. A. Wolf, Bowman Gray School of Medicine

An examination of several inductances relative to their use in the study of A.C. R. M. Helms, East Carolina College

Direct current characteristics of the string galvanometer. George W. Crawford, Davidson College

x*Passivity of partial differential systems.* Robert T. Herbst, Office of Ordnance Research, Durham

Panel discussion on *"The physics program in the small college."* William A. Parker, Catawba College; Paul A. Reichle, Lenoir-Rhyne College; H. E. Fulcher, Davidson College; R. M. Helms, East Carolina College

ZOOLOGY SECTION

x*A survey of North Carolina shrimp nursery grounds.* Austin B. Williams, Institute of Fisheries Research, U.N.C.

The validity of the scale method for small mouth bass of some Ozark streams of Missouri. Edward M. Lowry, Meredith College

x*Differential cold resistance and developmental rate of wild color strains of D. melanogaster.* M. E. Jacobs, Duke

x*The oxygen consumption of wild color strains of D. melanogaster as affected by temperature and humidity.* F. J. Vernberg, Duke

x*Rotenone resistance in the Mexican bean beetle.* Charles H. Brett, N.C. State

Varietal responses of carrots to the carrot rust fly. H. E. Scott, N.C. State

The phylogeny of the Veigaiidae (Acarina). Maurice H. Farrier, N.C. State

The influence of light on oyster setting. A. F. Chestnut, Institute of Fisheries Research, U.N.C.

The fall armyworm, Laphygma frugiperda (A. & S.), in North Carolina. A. T. Olive, N. C. State

When is a mocking bird not a "mockingbird"? Z. P. Metcalf, N.C. State

x*Some serological observations on fractions of Ehrlich ascites tumor cells.* Edward C. Horn and Mary Elizabeth House, Oak Ridge National Laboratory and Duke

Vertebrate remains from archaeological sites in the Tennessee valley of Alabama. Fred S. Barkalow, Jr., N.C. State

Backyard entomology. Tom Daggy, Davidson College

A Study of the Effects of Salmonella typhimurium on the Acquired Resistance of Mice to Trichinella spiralis. OSSIE MARIE BREWER. This study involved four groups of mice: the experimentals, the immune controls, the non-immune parasitic controls, and the non-immune bacteria controls. The experimentals and the immune controls were given three stimulating infections of 200 larvae each at intervals of three weeks, the experimentals having received bacteria concomitantly with the challenging infections. The non-immune parasitic controls and the non-immune bacteria controls received only the challenging infections of the larvae with the latter being simultaneously infected with *S. typhimurium*. The four groups of mice were killed for the extraction of the adult worms one week after the challenging infection.

The resulting average adult worm counts for each group, though with somewhat wide variations, showed a reduction in the number of worms recovered from both the experimentals and the control group which had received bacteria. This reduction must be mechanical and can be explained by the effect of the bacterium on the intestinal lining. Inflamation of the mucosa by *S. typhimurium* caused increased secretions, thereby preventing the worms from attaching themselves to the mucosa.

The results give an indication of the effect of *S. typhimurium* on the natural and acquired resistance of mice to *T. spiralis*. Further work is necessary, however, before more definite conclusions can be drawn.

*A Test of Specific Uptake from Organ Homogenates by Homologous Organs in the Young Mouse.** EDWARD C. HORN AND MARY ELIZABETH HOUSE. Weiss has demonstrated specific responses (weight increase, increased mitotic rate) of embryonic organs to homologous organ transplants, and Ebert, using radioactively tagged organ transplants, has shown that an increase in weight of the host organ under such conditions can best be interpreted as the incorporation from the grafts of tissue-specific proteins or of protein constituents larger than amino acids.

The present study was begun with the hope that the demonstration of the same effect in material large enough to allow tissue fractionation might lead to a better characterization of the chemical nature of the substance(s) transferred.

Tagged mouse proteins were prepared by incubating fasted adult mice with plant proteins labeled with radioactive carbon. Whole organ homogenates of pooled liver, kidney, spleen, and thymus were prepared and injected intraperitoneally into young (6-week-old) mice of the same strain. With one donor tissue (liver), crude fractionation of the homogenate into whole cells and nuclei, mitochondria and microsomes, and supernate was accomplished. The young hosts were sacrificed, the various organs homogenized, plancheted, and the dry residues counted.

The results showed no consistent indication of specific incorporation by the host organs of radioactive materials from the injected homologous tissue homogenates. The spleen consistently gave high uptake values suggesting that, per unit dry weight, it is a more effective organ than the liver for removing foreign protein from the circulation, an idea which, though not new, remains in dispute for other data.

A Technique for Measuring Prothrombin. JAMES W. FRESH, JOHN H. FERGUSON JESSICA H. LEWIS. Accurate prothrombin determinations are of value in the diagnosis of certain bleeding and clotting disorders, and in therapy by vitamin K and certain anticoagulants. Many techniques for allegedly measuring "prothrombin" have been devised. They depend essentially upon the formation of thrombin and the titration of this enzyme by measuring its effect on fibrinogen or other substrates. One-stage methods depend upon the rate of thrombin formation, whereas two-stage methods titer the total thrombin yield. Recent studies have shown that two other plasma factors: proaccelerin and proconvertin, vitally affect the rate and amount of thrombin formation from plasma in the presence of tissue thromboplastin and calcium.

The familiar "prothrombin time" (Quick, Stanley-Brown and Bancroft) measures prothrombin *only* when the concentrations of these other plasma factors are optimal. In order to obtain an accurate, simple and specific method for pro-

* This work was supported in part by a research grant (RG-4203) from the National Institutes of Health, Public Health Service.

thrombin assay, we have modified this one-stage procedure so that the concentrations of fibrinogen, proconvertin and proaccelerin are standardized. This method (Method I) has proved simple and versatile and has been adapted to include a micromodification, utilizing capillary blood.

A somewhat more complicated two-stage procedure (Method III) was also developed in which prothrombin was quantitatively isolated from plasma (or serum) by adsorption on to barium sulfate and elution with 0.1 M sodium citrate. The eluted prothrombin was then converted to thrombin by addition of optimal amounts of (pro)accelerin, proconvertin, buffers, tissue thromboplastin and calcium, and the total thrombin assayed.

These two techniques have been compared with a modification (Method II) of the original two-stage procedure (Warner, Brinkhous and Smith), in which both proconvertin and accelerin were added in optimal amounts.

"Prothrombin times" and prothrombin assays by the three methods were carried out on over 250 plasma specimens obtained from normal subjects, from newborns, and from patients suffering from a wide variety of illnesses. The comparison indicated that each of the "specific" methods was measuring the same thing with a high degree of accuracy. The correlation coefficient in each case was greater than 0.95. The correlation coefficient between results obtained by the "prothrombin time" (unmodified) and Method II was only 0.5.

In conclusion, the "prothrombin time" was shown to be a useful measure of blood coagulability, but not a specific assay of prothrombin. The three prothrombin assays were reliable, relatively simple and accurate and have proved their value in clinical tests.

Pyrimidines as Antagonists of Maleic Hydrazide. VICTOR A. GREULACH. Pea seeds were soaked 24 hours in 5×10^{-4} M maleic hydrazide (MH) either alone or in combination with 10^{-3} M concentrations of the following metabolites: uracil, thymine, thiouracil, hypoxanthine, adenine, adenosine, guanine, ribose, DNA and RNA. The seeds were then planted in quartz sand, watered with complete mineral nutrient solution, and allowed to grow in the dark for a week. The only substances which counteracted MH growth inhibition significantly were the pyrimidines: thymine, uracil, and thiouracil, and these had no significant effect in some experiments. Using the t test, thymine was found to produce significant effects in all four experiments, uracil in one experiment out of four, and thiouracil in three out of four. In no case did the pyrimidines completely counteract MH growth inhibition. The mean height of the control pea plants was 7.7 cm., that of the MH-treated plants 3.4 cm., and that of the plants also treated with uracil, thymine and thiouracil 5.4, 5.1 and 4.6 cm. respectively. The results suggest that one, but not the only, effect of MH may be interference with the pyrimidine metabolism of the plants. This is theoretically plausible since MH belongs to the related pyridazine group of compounds and is an isomer of uracil. However, these preliminary results are to be considered as suggestive rather than in any way conclusive.

Internal Structure of the Swimming Cell of Some Aquatic Fungi. WILLIAM J. KOCH. The internal structure of the body of the zoospores of ten species of chytrids (*Rhizophidium sphaerotheca*, *Rhizophlyctis petersenii*, *Entophlyctis* sp. (?), *Phlyctochytrium* (species "GH2"), *Phlyctochytrium* (species "La6b"), *Chytridium* (species "CH106"), *Catenochytridium carolinianum*, *Nowakowskiella* sp., *Septochytrium variabile* and *Rozella allomycis*) and of *Allomyces* has been studied in fixed and stained as well as in living and active spores from thalli growing on a variety of substrata. Each species has characteristic internal parts and a characteristic arrangement of these parts. Two cytological entities heretofore undescribed have been identified: "side granules" in *Nowakowskiella* and *Allomyces*, and "extranuclear granules" in all species. A second, non-functional and perhaps vestigial blepharoplast has been found in *Rhizophidium*, *Chytridium*, *Catenochytridium*, *Nowakowskiella* and *Septochytrium*. Also, the flagellum may be subapically, laterally or sub-basally attached in *Rhizophlyctis*, *Entophlyctis* (?) and *Phlyctochytrium* (species "La6b"). These two facts could suggest that the chytrids are derived at least in part from biflagellate ancestors. With the electron microscope the zoospores of *Rhizophidium* and *Chytridium* reveal structural details in the flagellum and blepharoplast which suggest homologies with comparable structures in bacteria.

Endosperm Development in Interspecific Crosses in Gossypium. J. B. WEAVER, JR. In various crosses between Asiatic ($n = 13$), American ($n = 26$) and synthetic hexaploids ($n = 39$) of cotton the endosperm was the first tissue to show abnormalities. In low-chromosome × high-chromosome crosses the endosperm made rapid initial growth but degenerated 10–20 days after pollination without ever developing cell walls. The wider the chromosome ratio the more rapid was the degeneration. Dumb-bell-shaped nuclei were frequently seen which were due either to amitosis or more likely to chromosome bridges. The embryo often reached ⅕ normal size but did not differentiate properly. Maternal tissue of the ovule, however, developed in an almost normal manner.

In the reciprocal crosses, except for $6n \times 4n$, development was quite different. The endosperm formed cell walls prematurely and ceased growth after five days while the embryo grew at a normal rate for the first ten days and then growth lagged. The maternal tissue stopped growth immediately after the endosperm. When the egg cell was not fertilized, however, the endosperm grew at a normal rate and a large embryo-less ovule was produced. This indicates that the hybrid embryo causes some physiological unbalance which inhibits endosperm growth when both develop within the same ovule. There was evidence, however, which indicated that the normal endosperm in the embryo-less ovules produced a stimulus which influenced the growth of the embryos in the adjacent degeneration ovules.

False Broom Rape of Tobacco in North Carolina. ARTHUR KELMAN, G. B. LUCAS AND H. R. GARRISS. False broom rape, a root disease of undetermined cause, has

been found to be widely distributed on tobacco in North Carolina. During the period from 1951 to 1954 specimens of the disease were obtained from 17 counties. Symptoms appear below-ground on the roots of field-grown plants as masses of white succulent irregular outgrowths. These are variable in size and shape. Leaf-like structures from the hypertrophied tissues may occasionally emerge from the soil and develop chlorophyll. Affected plants are usually stunted. Successful grafts of abnormal root tissue were made to above-ground portions of healthy tobacco plants. From these grafted root tissues normal leaf and stem tissue developed; however, no visible symptoms of the disease appeared on the roots of the stocks. The possibility had been suggested that this disease was caused by *Corynebacterium fascians*; this pathogen is the causal agent of a similar disease known as leafy gall or witches' broom on tobacco and other hosts. However, in greenhouse tests the leafy outgrowths that appeared on roots of plants inoculated with *C. fascians* were restricted to the base of the stem and differed in appearance from those of false broom rape. Roots of healthy tobacco plants were immersed in a suspension of fragments of false broom rape tissue. The plants were potted and permitted to grow for 3 months. Symptoms of false broom rape were present on the roots of those plants that were treated with the suspension made from false broom rape tissue but not on check plants. Root inoculations with different bacterial isolates obtained from false broom rape tissue have thus far given negative results.

Puccinia graminis Infection on Berberis in North Carolina. ALBERT F. THIEL. *Berberis canadensis* and *Berberis vulgaris* were tied with telial material on wheat during the past five years. Negative results were obtained with telial material collected in North Carolina. Telial material on wheat was obtained from Roanoke, Virginia in the fall of 1953. This was tied to *B. canadensis* and *B. vulgaris* growing in my garden and at Freeman Mill. In early May of 1954, picnia and aecia appeared on *B. vulgaris*. A total of twenty-five leaves were infected. No infections occurred on *B. canadensis*.

It therefore seems reasonable to conclude that rust infections will take place if the telial material is viable and the weather conditions are favorable.

Causes of Remarkable Variations in Strophostyles Flowers. A. L. PICKENS. *Strophostyles* (twisted style) is remarkable for a keel twisted into a form like a comma or a question-mark. The edges, free in other species, are united by a fringe of finger-like projections that interlock somewhat like a zipper's teeth, making the keel a tube. In this, the S-shaped style works like the lead of an automatic pencil. Leaf-cutter bees, *Megachile*, wrap themselves in the twisted keel, much as musicians wrap themselves in Sousa helicon horns, causing the stigma to shoot from the end of the tube like the lead in an automatic pencil, marking the bee's back with pollen, and receiving pollen from previously visited flowers. Indications are that different species of bees may be developing different varieties, and certain forms, like *Galactia*, seem to represent a transition between the normal and the twisted keel.

Our Carolina species are *Strophostyles umbellata* and *S. helvola*, with perhaps a form of the latter which is broader-leafed, smaller-flowered, duller-colored, and very strophostylate, the keel being almost or quite sickle-shaped, the foliage lush, *S.h. belle-meadensis*.

An ecological herbarium in which is collected not only the flower, but also its pollinating animal, is appealed for as a botanical need in America.

Variation in the Genus Heliopsis (Compositae). T. RICHARD FISHER. The genus *Heliopsis* (family Compositae, tribe Heliantheae) is composed of thirteen species, ranging from eastern United States and southern Canada west to the Rocky Mountains, south through Mexico, Central America, and to Central Bolivia.

There has been a great deal of confusion in regard to the status of several taxa of the genus. The purpose of this investigation was to study the genus throughout its entire range in order to gain information concerning the relationships of the species of the genus. The problem was attacked in three ways: by a study of available herbarium material, by growing and studying as many races as possible in the research garden, and by studying natural populations. These techniques involved conducting a hybridization program, a cytological study, and an investigation of the ecological conditions throughout the range of the species. The biosystematic treatment was limited to the species of the United States.

The over-all pattern of variation in the *H. helianthoides* complex of the United States is vast and multi-dimensional. The petiole length, leaf base angle, peduncle length, head width and pubescence were studied in connection with the variation problem of *H. helianthoides*. Data for these characters were assembled from 2500 herbarium specimens borrowed from the major herbaria of the United States. Morphologically the three sub-species, *H. helianthoides* subsp. *helianthoides*, subsp. *occidentalis*, and subsp. *scabra* are quite distinct within their centers of distribution. From a quadrat study of herbarium material it is evident that subsp. *helianthoides* and subsp. *occidentalis* are connected by a broad band of intermediates, covering an area of several hundred miles. There is only slight intergradation of characters between subsp. *occidentalis* and subsp. *scabra* and none between subsp. *helianthoides* and subsp. *scabra*.

Two hypotheses are proposed to account for the variation pattern found to exist in *H. helianthoides*. First, natural selection alone may be considered as a possible explanation of the character gradients or clines. Secondly, extensive hybridization with repeated backcrossing where the ranges of the taxa overlap also seems likely on the basis of the present data.

The Influence of Water Uptake on Absorption of Phosphorus by Corn Plants. RICHARD C. SMITH. Corn seeds were germinated in distilled water and then grown in constantly changing one-tenth strength Hoagland's solution to an age of eleven days. On the twelfth and thirteenth days they were then given full strength Hoagland's solution containing no phosphate.

On the fourteenth day the plants were placed individually in large test tubes containing Hoagland's solution and radioactive phosphorus as phosphate (P^{32},

0.1 μc/ml). One half the plants were placed in tubes which contained, in addition to the nutrient, NaN_3 (0.001 M). The plants were then placed in environments which would either favor or depress transpiration. Water uptake was determined by loss in weight of the plant and tube over the experimental period of six hours. At the end of this period the plants were removed, rinsed, weighed, and dried. They were then cut up and counted for radioactivity.

These experiments demonstrated that increased transpiration and the resulting water uptake cause an increase in the rate of phosphorus uptake. Treatment of roots with azide decreased phosphorus uptake and translocation to the shoot. These results suggest that uptake and translocation to the shoot of the plant are regulated by at least two major factors: metabolic accumulation and water uptake. It appears also that these two regulating factors can act independently and further that the rate of water uptake may influence the rate of metabolic accumulation.

Geology of Granville County, North Carolina. RICHARD J. COUNCILL. The predominant rocks of Granville County belong to various units of the Volcanic-Slate Series (lower Paleozoic?) and consist principally of fine- to medium-grained pyroclastic and epiclastic rocks, sometimes metamorphosed to phyllonite and sericite schist, and acid and basic volcanic flow rocks, including a rather extensive amygdaloidal rhyolite flow. The rocks are sometimes partially granitized near contacts with igneous masses. Rocks of the Volcanic-Slate Series are widely distributed in the northern and western two-thirds of the county.

Granitoid rocks of medium-to-coarse texture and ranging in composition from quartz-monzonite to gabbro (late Paleozoic?) interrupt the east-west continuity of the volcano-sedimentary rocks in the central and east-central portions of the county, while a wedge of arkosic sandstones and mudrocks (upper Triassic) intervenes to the south.

An ultramafic body, some seven miles in length and one-fourth to one mile in width, is associated with the intrusive rocks in the southeastern part of the county. This material consists of a central core of high-iron chromite surrounded by pyroxenite, the pyroxenite being largely altered to a gray-to-white soapstone. The entire body is enclosed by a narrow "ring" of coarse-grained gabbro which grades rather rapidly into less basic intrusives.

The extreme southeastern corner of the county is underlain by hornblende and mica gneisses and schists (pre-Cambrian?) which do not appear genetically related to either the Volcanic-Slate Series or the granitoid bodies.

Intrusive into all the rock units and quite prominent along contact zones are narrow diabasic and even-textured basic dikes of gabbro composition (upper Triassic).

A Report on the Mineralogy of the Triassic Durham Basin of Northern Wake County, North Carolina. W. H. DUHLING, JR. Twenty-four minerals or mineral groups were identified. Of these, only one, ilmenite, was present in all fractions of the sample. In the fractions in the specific gravity range between 2.965 and

4.00, epidote, kyanite and quartz were ubiquitous. The minerals in decreasing order of abundance are: grains too stained to identify, ilmenite, epidote, hematite, pyrite, leucoxene, quartz, tremolite-actinolite, kyanite, hypersthene-enstatite, hornblende, limonite, zircon, sillimanite, sphene, rutile, staurolite, alterite, garnet, aegerinaugite, monazite, orthite, augite, and diopside.

Petrography of the Sampson County, North Carolina, Pleistocene Formations. C. EDWARD HOWARD. The Pleistocene terraces of Sampson County, North Carolina, were mapped and the terrace deposits were sampled. In this area the Talbot and Wicomico terraces are apparently largely fluvial while the Sunderland and Coharie are apparently of marine origin. Mechanical analysis and mineral studies, as well as topography, indicate that the source of the Pleistocene sediments was primarily from the formations immediately underlying the area. Ilmenite and leucoxene are the dominant heavy minerals, together composing as much as 60 per cent, or more, of the heavy minerals present. Heavy mineral concentration in the sands, however, was not great enough to be considered of economic value. Clays, sands and gravels are available for structural materials.

The Determination of Radioactive Opaque Minerals in Black Sands. WARREN G. STEEL. Opaque radioactive minerals in black sand are neither readily identified by ordinary petrographic methods nor easily isolated by gravity, magnetic or electrostatic techniques. It has been found that hot hydrofluoric acid produces a green insoluble fluoride coating on opaque minerals containing uranium, a similar white coating on opaque thorium-bearing minerals and on those minerals with a high calcium content a white calcium fluoride coating. In every instance that a green or white coating was produced on an opaque mineral, the mineral was found to be radioactive. Monazite, xenotime, thorite and zircon are not affected by this HF treatment while with samarskite, euxenite, fergusonite, brannerite etc. excellent results were obtained.

Gold Deposits of Union County, North Carolina. SAM E. PHIFER. Gold was mined in Union County intermittently from around 1800 until about 1940. The chief deposits lie within a roughly crescent-shaped belt which extends from the southwestern to the northwestern corners of the county, paralleling its western boundary. The mines and prospects can be divided into two groups; The Lewis Group, about ten miles northwest of Monroe, The Grand Union Group, lying about eight miles west of Monroe, and other less important workings which are scattered throughout the northern, northwestern, western, and southwestern parts of the county. The country rock is a slate (Monroe) of the Volcanic-Slate Series which trend northeastward. The deposits are of three types; gold-quartz-sulphide lodes, placers along the present streams, and residual deposits.

The Physics of Nuclear Reactors. RAYMOND L. MURRAY. Two examples are presented of novel aspects of physical principles and methods used in the design of nuclear reactors.

(a) The speed distribution of the low-energy neutrons that produce nuclear fission of uranium is governed by the familiar Maxwell-Boltzmann distribution for gases

$$n(v) = n_0 A v^2 \exp(-mv^2/2kT)$$

The average fission cross-section of uranium in a Maxwellian flux

$$\bar{\sigma} = \int \sigma_f(v) n(v) v \, dv \Big/ \int n(v) v \, dv$$

was computed from recent measurements of $\sigma_f(v)$ by the French (similar data are classified in this country). $\bar{\sigma}$ is found to be 0.975 times the value expected if the fission cross-section were of the $1/v$ type with the same cross-section at the peak of the distribution, 2200 m/sec.

(b) An important radiation hazard from a high-power reactor cooled with water is the decay gamma ray from N^{16}, formed by high-energy neutron bombardment of O^{16},

$${}_8O^{16} + {}_0n^1 \rightarrow {}_7N^{16} + {}_1H^1 \qquad \text{(threshold 10 Mev)}$$

and decaying according to

$${}_7N^{16} \rightarrow {}_8O^{16} + {}_{-1}e^0 + \gamma + 6 \text{ Mev} \qquad \text{(7 sec half-life)}$$

The generation rate of N^{16} per unit volume was calculated from (1) the neutron flux distribution in energy (obtained from the energy dependent neutron transport equation and the fission spectrum), and (2) the measured reaction cross-section as a function of energy. The result was $g = 2.4 \times 10^{-5} F(N_O/N_H)$ where F is the fast neutron production density; N_O and N_H are atom densities of water oxygen and reactor hydrogen. For a power level of one megawatt, a five foot concrete shield was found necessary to protect against the radiations from activated cooling water.

Passivity of Partial Differential Systems. ROBERT TAYLOR HERBST. The conditions necessary for the *passivity* of a partial differential system are given. It is shown that Maxwell field equations can be put in regular passive form if the continuity equation is satisfied and if the electric field vector satisfies the wave equation. A similar result is obtained for the magnetic field vector.

A Survey of North Carolina Shrimp Nursery Grounds. AUSTIN B. WILLIAMS. The penaeid shrimp nursey grounds in North Carolina can be divided into four areas on the basis of juvenile population densities and specific composition. In general, the highest concentration of juveniles occurs in the shallow portions of estuaries from Brunswick County northeastward through the seaward side of Carteret County, and in the shoal parts of northern Pamlico Sound. With one exception, sparse populations occur in regions of weak current and no perceptible tide. The fisheries for *Penaeus duorarum* and *P. setiferus* may occur near the nursery ground for the species. The relationship of the adult *P. aztecus* population to its nursery ground is obscure.

Differential Cold Resistance and Developmental Rate of Wild Color Strains of Drosophila melanogaster. M. E. JACOBS. Dark and light color strains of *Drosophila melanogaster* were isolated from a sample of flies collected from a wild population at Beaufort, N. C. When pupae of the two strains were subjected to a temperature of −1.5°C. for 1–3 days, it was found that pupae from the light strain had a higher survival rate than did pupae of the dark strain. Studies of developmental rate showed the light strain to develop more rapidly than the dark strain.

The Oxygen Consumption of Wild Color Strains of Drosophila melanogaster as Affected by Temperature and Humidity. F. J. VERNBERG. The rate of oxygen uptake of dark and light forms of adults and pupae of *Drosophila melanogaster* was determined at different temperatures and at different humidities. At 13°C., 18°C., 22°C., and 39°C. adults of both color strains utilized oxygen at about the same rate when humidity was kept high. However, at temperature levels of 27°C., 30°C., 33°C., and 36°C the light form consumed the most oxygen per unit weight and time.

Pupae of dark, light and intermediate forms consumed oxygen at about the same level at 13°C., but at 25°C., 30°C., and 35°C. the dark form was consistently lower with the intermediate strain having the highest value at 35°C.

Low humidity stimulated the rate of oxygen consumption of adults and pupae of both forms.

The possible significance of these findings in the geographical distribution, ecological relationships, and genetics of the population of these forms was discussed.

Rotenone Resistance in the Mexican Bean Beetle. CHARLES H. BRETT. Field test data taken during 1951, 1953, and 1954 showed that rotenone dusts gave good control of the Mexican bean beetle at Norfolk, Virginia but were ineffective at Mills River, North Carolina. Laboratory tests with field collected 3rd or 4th instar larvae from these areas substantiated the differences. Beetles from Mills River, N. C. reared in the laboratory showed resistance in the F3 generation similar to the P1, thus eliminating the possibility of climate or other interrelated factors.

*Some Serological Observations on Fractions of Ehrlich Ascites Tumor Cells.** EDWARD C. HORN AND MARY ELIZABETH HOUSE. A single intraperitoneal injection of nucleoprotein extracted from Ehrlich ascites cells into mice three or four weeks prior to a tumor challenge produces a significant decrease in their mean survival time. Other data already reported implicate an immune system. Rabbit antisera to different fractions of the ascites cells have been prepared. Stable suspensions of ascites cells and ascites nuclei have been prepared and tested against dilutions of the various antisera for agglutination. The details of these results will be elaborated on.

* This work was supported in part by a research grant (RG-4203) from the National Institutes of Health, Public Health Service.

PROCEEDINGS OF THE ELISHA MITCHELL SCIENTIFIC SOCIETY
1954–1955

514th MEETING, OCTOBER 12, 1954

R. L. INGRAM (Geology): *X-ray Diffraction Studies of North Carolina Clays.*
IRA FOWLER (Anatomy): *The Role of the Neural Tube and the Notochord in the Development of the Axial Skeleton of the Chick.*

Nineteen full members and fifty-six associate members were received into the Society. President W. C. George made a brief report on the financial condition of the *Journal*.

515th MEETING, NOVEMBER 9, 1954

MORRIS DAVIS (Physics): *Report on the 1954 Solar Eclipse Expedition.*
H. G. MCCURDY (Psychology): *A Critique of ESP Research.*

After a report by Dr. J. N. Couch on the financial condition of the *Journal*, it was decided that the Officers of the Society should meet with the Editorial Board in order to examine ways in which the Society could increase its financial support for the *Journal*.

516th MEETING, DECEMBER 14, 1954

R. C. BOSE (Mathematical Statistics): *The Design of Experiments.*
J. F. BUNNETTE (Chemistry): *Some Unusual Aromatic Substitution Reactions.*

517th MEETING, JANUARY 11, 1955

FRANK WILLIAMS (Medicine): *Response of the Human Red Cell to Changes in Osmotic Pressure.*
MARY ESTHER GAULDEN (Botany): *The Effects of Radiation on Living Cells.*

Dr. J. C. Morrow, reporting the recommendation of the Officers and Editorial Board of the Society concerning the *Journal*, moved that the *Journal* receive from the Society a gift of $350.00, $94.50 of which should come from cashing the U.S. Bond held by the Society and the remainder from the checking account; furthermore, that 75 per cent of the yearly surplus be given to the *Journal*, the surplus to be calculated as the difference between receipts and expenses as of the May meeting. The motion was seconded by Dr. Walter Hartung and passed by unanimous vote of the members present.

518th MEETING, FEBRUARY 8, 1955

E. MERTZBOCHER (Physics): *Polarization in High Energy Scattering and the Nuclear Shell Model.*
F. BURTON JONES (Mathematics): *An Elementary Two-Color Problem.*

519th MEETING, MARCH 8, 1955

D. W. ABSE (Psychiatry): *Clinical Research in Schizophrenic Disease.*
W. DEMERITT (Pediodonics): *Preventive Dentistry.*

Dr. J. C. Morrow reported that the actual revenue from the Society's War Bond was $98.00, and that this amount, together with $252.00 from the Society's checking account, had been given to the *Journal*.

520th MEETING, APRIL 12, 1955

G. R. MACCARTHY (Geology): *Geophysical Researches in Arctic Alaska.*
CLAUDE PIANTADOSI (Pharmacy and Biochemistry): *Chemistry of the Acetal Phosphatides.*

Dr. Paul Shearin moved: Resolved that, upon retirement from the University, a member be permitted the option of assuming an emeritus status in which he would pay no dues, and receive notices of meetings but not the *Journal*. This motion was seconded by Dr. J. N. Couch and passed by unanimous approval of the members present.

521st MEETING, MAY 10, 1955

F. W. STALLARD (Mathematics): *Differential Systems with Interface Conditions.*

At the beginning of the meeting Dr. W. R. Mann, Vice-President, presented a certificate and a check for $50.00 to Mr. F. W. Stallard, as winner of the William Chambers Coker Award in Science for the year 1954–1955.

The Treasurer's report was read and the accounts reported in order by the Auditing Committee (A. E. Radford and R. L. McKee).

The Nominating Committee (C. W. Hooker, Harold Hotelling, and J. N. Couch, Chairman) presented the following slate of nominees for the year 1955–56:
President—Walter Hartung
Vice-President—F. Burton Jones
Secretary-Treasurer—Harold McCurdy
Member of the Editorial Board—C. D. Beers, to take the place of W. C. George who retired from this position by his own wish.

The slate was unanimously elected.

J. C. MORROW, *Sec.-Treas.*

PROOF OF THE SUM AND DIFFERENCE FORMULAS IN TRIGONOMETRY

BY T. F. HICKERSON

Department of Mathematics, University of North Carolina, Chapel Hill, North Carolina

Treating the various triangles in Figs. 2–7 as closed traverses, where of course $\sum x = 0$ and $\sum y = 0$, and noting that the horizontal and vertical projections (Fig. 1) are $x = d \cos \theta$, $y = d \sin \theta$, in which d is the length of line and θ is

the angle it makes with the X-axis; we proceed as follows (with strict adherence to the established rules of the subject):

ODQ (*Fig. 2*)	*Distance*	*Angle*	x	y
OD	$\cos\beta$	α	$\cos\beta\cos\alpha$	$\cos\beta\sin\alpha$
DQ	$\sin\beta$	$\alpha + 90°$	$-\sin\beta\sin\alpha$	$\sin\beta\cos\alpha$
QO	1	$180 + (\alpha + \beta)$	$-\cos(\alpha + \beta)$	$-\sin(\alpha + \beta)$
			Sum = 0	0

From $\sum y = 0$; $\sin(\alpha + \beta) = \sin\alpha\cos\beta + \cos\alpha\sin\beta$ (a)

From $\sum x = 0$; $\cos(\alpha + \beta) = \cos\alpha\cos\beta - \sin\alpha\sin\beta$ (b)

OQ'D (*Fig. 2*)	*Distance*	*Angle*	x	y
OQ'	1	$(\alpha - \beta)$	$\cos(\alpha - \beta)$	$\sin(\alpha - \beta)$
Q'D	$\sin\beta$	$\alpha + 90$	$-\sin\beta\sin\alpha$	$\sin\beta\cos\alpha$
DO	$\cos\beta$	$180 + \alpha$	$-\cos\beta\cos\alpha$	$-\cos\beta\sin\alpha$
			Sum = 0	0

From $\sum y = 0$; $\sin(\alpha - \beta) = \sin\alpha\cos\beta - \cos\alpha\sin\beta$ (c)

From $\sum x = 0$; $\cos(\alpha - \beta) = \cos\alpha\cos\beta + \sin\alpha\sin\beta$ (d)

ODQ (*Fig. 3*)	*Distance*	*Angle*	x	y
OD	1	α	$\cos\alpha$	$\sin\alpha$
DQ	$\tan\beta$	$\alpha + 90$	$-\tan\beta\sin\alpha$	$\tan\beta\cos\alpha$
QO	r	$180 + (\alpha + \beta)$	$-r\cos(\alpha + \beta)$	$-r\sin(\alpha + \beta)$
			Sum = 0	0

From $\sum y = 0$; $r\sin(\alpha + \beta) = \sin\alpha + \cos\alpha\tan\beta$ (f)

From $\sum x = 0$; $r\cos(\alpha + \beta) = \cos\alpha - \sin\alpha\tan\beta$ (g)

Divide (f) by (g);

$$\tan(\alpha + \beta) = \frac{\sin\alpha + \cos\alpha\tan\beta}{\cos\alpha - \sin\alpha\tan\beta} = \frac{\tan\alpha + \tan\beta}{1 - \tan\alpha\tan\beta} \quad \text{(h)}$$

In a similar manner, from *OQ'D* (Fig. 3), we get

$$\tan(\alpha - \beta) = \frac{\tan\alpha - \tan\beta}{1 + \tan\alpha\tan\beta} \quad \text{(i)}$$

From *ODQ* (Fig. 4) and *OQ'D* (Fig. 4), we get

$$\cot(\alpha + \beta) = \frac{\cot\alpha\cot\beta - 1}{\cot\alpha + \cot\beta} \quad \text{(j)}$$

$$\cot(\alpha - \beta) = \frac{\cot\alpha\cot\beta + 1}{-\cot\alpha + \cot\beta} \quad \text{(k)}$$

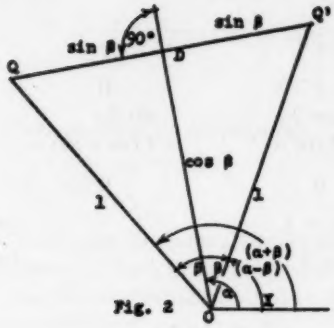

Fig. 2

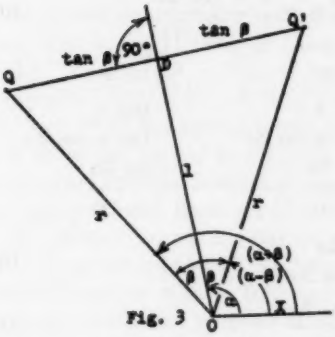

Fig. 3

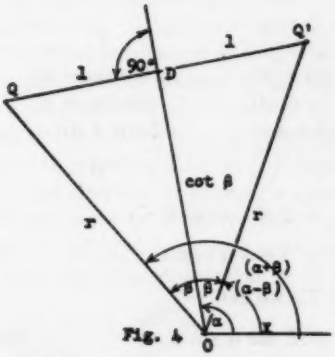

Fig. 4

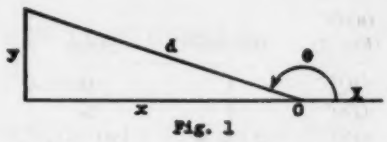

Fig. 1

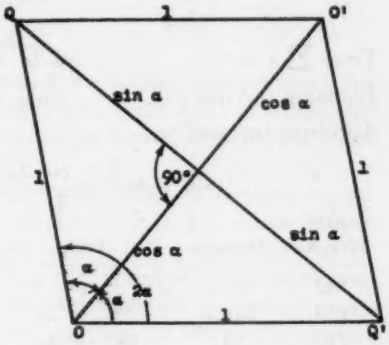

Fig. 5

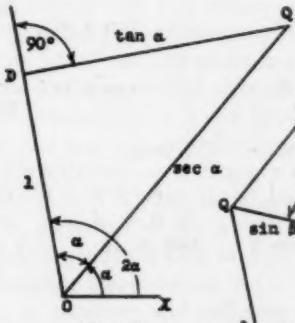

Fig. 6

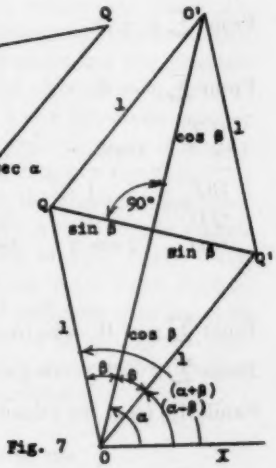

Fig. 7

OQ'Q (*Fig. 5*)	*Distance*	*Angle*	*x*	*y*
OQ'	1	0°	1	0
Q'Q	$2 \sin \alpha$	$90 + \alpha$	$-2 \sin^2\alpha$	$2 \sin \alpha \cos \alpha$
QO	1	$180 + 2\alpha$	$-\cos 2\alpha$	$-\sin 2\alpha$
			Sum = 0	0

From $\sum y = 0$; $\sin 2\alpha = 2 \sin \alpha \cos \alpha$ (l)

From $\sum x = 0$; $\cos 2\alpha = 1 - 2 \sin^2\alpha$ (m)

OQ'O' (*Fig. 5*)	*Distance*	*Angle*	x	y
OQ'	1	0	1	0
Q'O'	1	2α	$\cos 2\alpha$	$\sin 2\alpha$
O'O	$2 \cos \alpha$	$180 + \alpha$	$-2 \cos^2\alpha$	$-2 \cos \alpha \sin \alpha$
			Sum = 0	0

From $\sum x = 0$; $\cos 2\alpha = 2 \cos^2\alpha - 1$ (n)

Equating (m) and (n), $\sin^2\alpha + \cos^2\alpha = 1$ (o)

Also from (m) and (n),

$$\sin^2 \alpha = \frac{1 - \cos 2\alpha}{2}; \quad \cos^2 \alpha = \frac{1 + \cos 2\alpha}{2} \qquad (p)$$

OQD (*Fig. 6*)	*Distance*	*Angle*	x	y
OQ	$\sec \alpha$	α	1	$\tan \alpha$
QD	$\tan \alpha$	$90 + 2\alpha$	$-\tan \alpha \sin 2\alpha$	$\tan \alpha \cos 2\alpha$
DO	1	$180 + 2\alpha$	$-\cos 2\alpha$	$-\sin 2\alpha$
			Sum = 0	0

From $\sum y = 0$; $\tan \alpha = \dfrac{\sin 2\alpha}{1 + \cos 2\alpha}$ (q)

From $\sum x = 0$; $\tan \alpha = \dfrac{1 - \cos 2\alpha}{\sin 2\alpha}$ (r)

OQ'O' (*Fig. 7*)	*Distance*	*Angle*	x	y
OQ'	1	$\alpha - \beta$	$\cos (\alpha - \beta)$	$\sin (\alpha - \beta)$
Q'O'	1	$\alpha + \beta$	$\cos (\alpha + \beta)$	$\sin (\alpha + \beta)$
O'O	$2 \cos \beta$	$180 + \alpha$	$-2 \cos \beta \cos \alpha$	$-2 \cos \beta \sin \alpha$
			Sum = 0	0

From $\sum y = 0$; $\sin (\alpha + \beta) + \sin (\alpha - \beta) = 2 \sin \alpha \cos \beta$ (s)

From $\sum x = 0$; $\cos (\alpha + \beta) + \cos (\alpha - \beta) = 2 \cos \alpha \cos \beta$ (t)

Similarly, from the closed traverse *OQ'Q*, (Fig. 7), we get

$$\sin (\alpha + \beta) - \sin (\alpha - \beta) = 2 \cos \alpha \sin \beta \qquad (u)$$

$$\cos (\alpha + \beta) - \cos (\alpha - \beta) = 2 \sin \alpha \sin \beta \qquad (v)$$

As a check, (s) + (u) = (a); (t) + (v) = (b).

CONCLUSIONS.—These derivations are believed to be novel and new and simpler than those found in the 30 or more trig. texts examined. They also enable the student to see more clearly the general applicability of the formulas to angles of any size; and much needed practice in evaluating functions of $90° + \alpha$, $180° + \alpha$, etc., is introduced incidentally. Moreover this method tends to clarify a useful procedure for dealing with problems in surveying and navigation.

CONTINUOUS PRODUCTS IN LINEAR SPACES[1]

BY J. S. MAC NERNEY

Department of Mathematics, University of North Carolina, Chapel Hill, North Carolina

1. *Introduction*

This paper provides a continuation of some of the studies initiated in [6]. We assume S to be a linear normed complete space, with B the space of continuous linear transformations from S to S, and our notation here is consistent with our previous usage.

In [6], we established a *continuous product* representation for *harmonic operators*, $M(a, b) = {}_a\prod^b\{1 + dF\}$ as a Riemann-type limit in B, i.e., as the limit of $\prod_{i=1}^{n+1}\{1 + [F(t_i) - F(t_{i-1})]\}$ as $LUB \mid t_i - t_{i-1} \mid \to 0$ (for monotone number sequences $t = \{t_i\}_{i=1}^{n+1}$ such that $t_0 = a$ and $t_{n+1} = b$). There F was a continuous function from the real numbers to B, of bounded variation on each interval, and the study served to establish and classify solutions of certain linear (and non-linear) Stieltjes integral equations and to extend the known results on continuous continued fractions ([1] and [9]).

Our purpose here is to relax the requirement that F be continuous, and to develop an extended theory. This we accomplish by replacing the aforementioned limiting process with a Hellinger-type limit,[2] and by replacing the Stieltjes integrals with *mean integrals* analogous to those studied recently by Lane [5].[3]

An *ordered subdivision* of the ordered number pair a, b is a monotone number sequence $t = \{t_i\}_{i=1}^{n+1}$ such that $t_0 = a$ and $t_{n+1} = b$, and a *refinement* of t is an ordered subdivision of a, b of which t is a subsequence. If φ is a function from the collection of ordered subdivisions of a, b to B, then the *Hellinger-type limit* of φ (abbreviated as: *H-limit* of φ) is an element T of B such that if c is a positive number there is an ordered subdivision s of a, b such that $\mid T - \varphi(t) \mid < c$ for each refinement t of s; it follows from the completeness of the space B that, in order that the H-limit of φ exist, it is necessary and sufficient that for each positive number c there exist an ordered subdivision s of a, b such that $\mid \varphi(s) - \varphi(t) \mid < c$ for each refinement t of s. For example, suppose the function F from the number interval $[a, b]$ to B is of bounded variation:

$$V\{[a, b], F\} = \int_a^b \mid dF \mid \text{ is the H-limit at } a, b \text{ of } \sum_t \mid dF \mid$$

$$= \sum_{i=1}^{n+1} \mid F(t_i) - F(t_{i-1}) \mid.$$

[1] Presented to the American Mathematical Society on November 26, 1954.

[2] This notion of limit is included in the studies made by E. H. Moore and H. L. Smith in [7]: as indicated there, the idea stems from the work of E. D. Hellinger ([2], p. 234 ff. of [3]), whose integrals generalized the Stieltjes theory of integration.

[3] These integrals were among those defined by H. L. Smith [8], and were investigated by H. S. Kaltenborn [4] in the case of real-valued functions. The treatment by R. E. Lane [5] embraces complex-valued functions, and many of his theorems are readily extended to the present context.

2. *Continuous Products*

If, for each natural number n, T_n is an element of B, then ${}_{i=1}\prod^{1} T_i = T_1$ and, for $n = 1, 2, \cdots$, ${}_{i=1}\prod^{n+1} T_i = \{{}_{i=1}\prod^{n} T_i\} T_{n+1}$. If F is a function from the real numbers to B and a, b is an ordered number pair, the *continuous product* ${}_{a}\prod^{b}\{1 + dF\}$ is the H-limit at a, b of $\prod_t\{1 + dF\}$, where

$$\prod_t\{1 + dF\} = {}_{i=1}\prod^{n+1}\{1 + [F(t_i) - F(t_{i-1})]\} \qquad \text{for } t = \{t_i\}_{i=1}^{n+1}.$$

The following inequality is fundamental in the study of continuous products, and variations of it will be used repeatedly: if $A_1, \cdots, A_{n+1}$ and $B_1, \cdots, B_{n+1}$ are sequences of elements of B then

$$(2.1) \quad |\, {}_{i=1}\prod^{n+1}\{1 + A_i\} - {}_{i=1}\prod^{n+1}\{1 + B_i\}\,| \leq \operatorname{Exp}\left(\sum_{i=1}^{n+1}\{\,|A_i| + |B_i|\,\}\right)\sum_{i=1}^{n+1}|A_i - B_i|\,.$$

We note that, if a, b, c is a monotone number sequence and each of ${}_{a}\prod^{b}\{1 + dF\}$ and ${}_{b}\prod^{c}\{1 + dF\}$ exists, then ${}_{a}\prod^{c}\{1 + dF\}$ exists and is ${}_{a}\prod^{b}\{1 + dF\}{}_{b}\prod^{c}\{1 + dF\}$; moreover, ${}_{a}\prod^{a}\{1 + dF\} = 1$.

We have previously established the following theorem (see section 3 of [6]), and the result will be needed here.

THEOREM 2.1. Suppose F is a continuous function from the real numbers to B and F is of bounded variation on each interval. If I is an interval and c is a positive number there is a positive number k such that if a, b is an ordered pair of numbers in I and $t = \{t_i\}_{i=1}^{n+1}$ is an ordered subdivision of a, b and $|\, t_i - t_{i-1}\,| < k$ for $i = 1, \cdots, n + 1$ then $|\, {}_{a}\prod^{b}\{1 + dF\} - \prod_t\{1 + dF\}\,| < c$; moreover, the function M, $M(r, s) = {}_{r}\prod^{s}\{1 + dF\}$ for each ordered number pair r, s, is continuous from the number plane to B and $M(r, s)M(s, r) = 1$ for all r and s.

THEOREM 2.2. Suppose F is a continuous function from the number interval $[a, c]$ to B and F is of bounded variation on $[a, c]$. If each of K and L is an element of B and b is a number in the segment (a, c) and $G(r) = F(r)$, $G(b) = F(b) + K$, and $G(s) = F(s) + K + L$ for r in $[a, b)$ and s in $(b, c]$, then the following formulas hold:

$$(2.2) \quad \begin{aligned} {}_{a}\prod^{b}\{1 + dG\} &= {}_{a}\prod^{b}\{1 + dF\}\,(1 + K), \\ {}_{b}\prod^{c}\{1 + dG\} &= (1 - K){}_{b}\prod^{c}\{1 + dF\}, \\ {}_{b}\prod^{c}\{1 + dG\} &= (1 + L){}_{b}\prod^{c}\{1 + dF\}, \text{ and} \\ {}_{a}\prod^{b}\{1 + dG\} &= {}_{a}\prod^{b}\{1 + dF\}\,(1 - L). \end{aligned}$$

Proof is omitted since this follows directly from the preceding theorem. We observe that, under the hypothesis above,

$$(2.3) \quad \begin{aligned} {}_{b}\prod^{c}\{1 + dG\}{}_{a}\prod^{b}\{1 + dG\} &= 1 - K^2, \text{ and} \\ {}_{b}\prod^{c}\{1 + dG\}{}_{a}\prod^{b}\{1 + dG\} &= 1 - L^2. \end{aligned}$$

THEOREM 2.4. If F is a function from the real numbers to B, of bounded

variation on each interval, then ${}_a\prod^b\{1 + dF\}$ exists for each ordered number pair a, b.

PROOF. Suppose F is a function from the real numbers to B, of bounded variation on each interval, such that $F(0) = 0$. There is a simple number sequence $r_1, r_2, \cdots$ such that if s is a number at which F is not continuous then there is a natural number n such that $r_n = s$. There is a sequence $F_1, F_2, \cdots$ of functions from the real numbers of B such that

(i) for each natural number n, F_n is of bounded variation on each interval and $F_n(0) = 0$,

(ii) F_1 is continuous and, if n is a natural number and $[a, b]$ is a number interval which does not contain r_n, then $F_{n+1}(b) - F_{n+1}(a) = F_n(b) - F_n(a)$, $F_{n+1}(r_n) - F_{n+1}(r_n-) = F(r_n) - F(r_n-)$, and $F_{n+1}(r_n+) - F_{n+1}(r_n) = F(r_n+) - F(r_n)$, and

(iii) for each interval I, $V\{I, F_n - F\} \to 0$ as $n \to \infty$.

For each natural number n, let M_n be the function defined by: $M_n(r, s) = {}_r\prod^s\{1 + dF_n\}$ for each ordered number pair r, s; we note that if n is a natural number and r_n is a number in the segment (a, c) then the formulas (2.2) and (2.3) hold with $b = r_n$, $G = F_{n+1}$, $K = F(r_n) - F(r_n-)$, $L = F(r_n+) - F(r_n)$, and F replaced by F_n. Suppose I is a number interval and c is a positive number, and let D be a number such that $V\{I, F_n\} + V\{I, F\} \leq D$ for $n = 1, 2, \cdots$. If a, b is an ordered pair of numbers in I and p and q are natural numbers then, by (2.1), $| M_p(a, b) - M_q(a, b) | \leq \text{Exp}\,(V\{I, F_p\} + V\{I, F_q\})V\{I, F_p - F_q\}$; hence there is a function M such that

$$| M_n(a, b) - M(a, b) | \leq \text{Exp}\,(V\{I, F_n\} + V\{I, F\})\cdot V\{I, F_n - F\}$$

for all a, b in I and $n = 1, 2, \cdots$. Let n be a natural number such that $V\{I, F_n - F\} < \frac{1}{3}\, c\ \text{Exp}\,(-D)$. If a, b is an ordered pair of numbers in I there is an ordered subdivision s of a, b such that $| M_n(a, b) - \prod_t \{1 + dF_n\} | < \frac{1}{3}\, c$ for each refinement t of s, so that if t is a refinement of s then $| M(a, b) - \prod_t\{1 + dF\} | < c$. Thus $M(a, b) = {}_a\prod^b\{1 + dF\}$, and the proof is complete.

By argument similar to that of the preceding proof, we obtain the following theorem.

THEOREM 2.5. If $F_1, F_2, \cdots$ is a sequence of functions from the real numbers to B, each of bounded variation on the interval I, and F is a function from I to B such that $V\{I, F_n - F\} \to 0$ as $n \to \infty$, then F is of bounded variation on I and ${}_a\prod^b\{1 + dF_n\} \to {}_a\prod^b\{1 + dF\}$ in B as $n \to \infty$, uniformly for a and b in I.

As an elementary application of (2.1), one readily obtains the following theorem, which we state without proof.

THEOREM 2.6. Suppose F is a function from the real numbers to B, of bounded variation on each interval, $M(a, b) = {}_a\prod^b\{1 + dF\}$ for each ordered number pair a, b, and N is a number such that $V\{[1, b], F\} < N$ for each number $b > 1$. Then, for each number t, the limit $M(t, +\infty)$ exists (in B), and $M(t, +\infty) \to 1$ as $t \to +\infty$.

REMARKS. Suppose the function F, from the real numbers to B, is of bounded variation on each interval and $M(a, b) = {}_a\prod^b\{1 + dF\}$ for each ordered number pair a, b. If I is a number interval then

$$|M(a, b) - 1| \leq V\{I, F\} \operatorname{Exp}(V\{I, F\})$$

for all a and b in I; from this and the multiplicative property (Theorem 2.1), it follows that if Q is a bounded set of numbers then $M(r, s)$ is of bounded variation in r on each interval uniformly for s in Q and is of bounded variation in s on each interval uniformly for r in Q. From the uniformity of the convergence to M of the sequence $M_1, M_2, \cdots$ in the proof of Theorem 2.4, we see that for each number r: $M(r-, r) = 1 + [F(r) - F(r-)]$, $M(r, r-) = 1 - [F(r) - F(r-)]$, $M(r, r+) = 1 + [F(r+) - F(r)]$, and $M(r+, r) = 1 - [F(r+) - F(r)]$. Hence, in order that $M(a, b)M(b, a) = 1$ for each ordered pair a, b, it is necessary (and also sufficient) that

$$[F(r) - F(r-)]^2 = [F(r+) - F(r)]^2 = 0$$

for each number r. This condition is satisfied if, for example, F has the matric form,

$$F(r) = \begin{pmatrix} 0 & f(r) \\ g(r) & 0 \end{pmatrix} \quad \text{for each number } r,$$

where one of f and g is continuous from the left at each number and one of f and g is continuous from the right at each number. We postpone, until section 4, a closer scrutiny of these ideas.

3. *Mean Integrals*

If E, F, G is a triple of function from the real numbers to B, and $t = \{t_i\}_{i=0}^{n+1}$ is a monotone number sequence, then

$$\sum_t E \cdot G \cdot dF = \sum_{i=1}^{n+1} \frac{E(t_i) + E(t_{i-1})}{2} \frac{G(t_i) + G(t_{i-1})}{2} [F(t_i) - F(t_{i-1})],$$

$$\sum_t EG \cdot dF = \sum_{i=1}^{n+1} \frac{E(t_i)G(t_i) + E(t_{i-1})G(t_{i-1})}{2} [F(t_i) - F(t_{i-1})],$$

$$\sum_t E \cdot dF \cdot G = \sum_{i=1}^{n+1} \frac{E(t_i) + E(t_{i-1})}{2} [F(t_i) - F(t_{i-1})] \frac{G(t_i) + G(t_{i-1})}{2},$$

and $\sum_t dF \cdot EG$ and $\sum_t dF \cdot E \cdot G$ are defined similarly; if a, b is an ordered number pair then the *mean integrals* $\int_a^b E \cdot G \cdot dF$, $\int_a^b EG \cdot dF$, $\int_a^b E \cdot dF \cdot G$, $\int_a^b dF \cdot EG$ and $\int_a^b dF \cdot E \cdot G$ are the H-limits at a, b of the corresponding functions $\sum_t$.

We note that each of these mean integrals, subject to obvious existence requirements, is linear in each of E, F, and G; moreover, if a, b, c is an ordered number triple then $\int_a^a = 0$ and if two of $\int_a^b$, $\int_b^c$, and $\int_a^c$ exist then the third

exists and $\int_a^b + \int_b^c = \int_a^c$; finally, we have the integration by parts theorem: if either $\int_a^b F \cdot dG$ or $\int_a^b dF \cdot G$ exists then the other exists and their sum is $F(b)G(b) - F(a)G(a)$.

The function F, from real numbers to B, is *quasi-continuous* provided that, for each number s, each of the limits $F(s+)$ and $F(s-)$ exists. A *step-function* is a function from the real numbers to B such that if $[a, b]$ is a number interval there is an ordered subdivision t of a, b such that F is constant on each of the segments (t_{i-1}, t_i). We have already made use of the fact that a function which is of bounded variation on each interval is quasi-continuous. We note that a quasi-continuous function does not have an uncountable set of points of discontinuity; indeed, if F is quasi-continuous and $[a, b]$ is a number interval and c is a positive number, there exists an ordered subdivision t of a, b such that if r and s are numbers in one of the segments (t_{i-1}, t_i) then $| F(r) - F(s) | < c$. From this it follows that if F is quasi-continuous and I is a number interval and c is a positive number there is a step-function G such that $| F - G |_I < c$.[4]

NOTE. We suppose, for the rest of this section, that E, F, G is an ordered triple of functions from the real numbers to B, each of E and G is quasi-continuous, F is of bounded variation on each number interval, and $F(0) = 0$.

THEOREM 3.1. If a, b is an ordered number pair, each of the five mean integrals defined above exists.

Proof is omitted, since it may be easily constructed along the lines followed by Lane (Theorem 4.1 of [5]); the existence is readily established for the case that each of E and G is a step-function; indeed, if each of E and G is constant on the segment (a, b) then

$$\begin{aligned}\int_a^b E \cdot dF \cdot G = {} & \frac{E(a+) + E(a)}{2} [F(a+) - F(a)] \frac{G(a+) + G(a)}{2} \\ & + \frac{E(b-) + E(a+)}{2} [F(b-) - F(a+)] \frac{G(b-) + G(a+)}{2} \\ & + \frac{E(b) + E(b-)}{2} [F(b) - F(b-)] \frac{G(b) + G(b-)}{2}.\end{aligned} \tag{3.1}$$

THEOREM 3.2. Suppose φ is a function from the ordered number pairs to B, $\sum_t | \varphi | = \sum_{i=1}^{n+1} | \varphi(t_{i-1}, t_i) |$ for $t = \{t_i\}_{i=0}^{n+1}$, $[a, b]$ is an interval and φ satisfies the following conditions:

(i) if r is a number then $\varphi(r-, r) = \varphi(r, r+) = \varphi(r, r) = 0$, and

(ii) if $c > 0$ there is an ordered subdivision $s = \{s_i\}_{j=1}^{m+1}$ of a, b such that, if $\{(a_j, b_j)\}_{j=1}^{k+1}$ is a sequence of mutually exclusive segments and for each integer $j (1 \leq j \leq k+1)$ there is an integer $i (1 \leq i \leq m+1)$ such that the interval $[a_j, b_j]$ is a subset of the segment (s_{i-1}, s_i), then

$$\sum_{j=1}^{k+1} | \varphi(a_j, b_j) | < c.$$

Then $\sum_t | \varphi |$ has the H-limit 0 at a, b.

[4] The symbol $| E |_I$ denotes the LUB of $| E(r) |$ for r in I.

PROOF. Let c be a positive number and $s = \{s_i\}_{i=0}^{m+1}$ be an increasing ordered subdivision of a, b such that (ii) holds. By (i), there is a positive number d such that (for each $i = 1, \cdots, m+1$) $d < \frac{1}{2}(s_i - s_{i-1})$ and if p is in $(s_{i-1}, s_{i-1} + d]$ and q is in $[s_i - d, s_i)$ then $|\varphi(s_{i-1}, p)| < c/(m+1)$ and $|\varphi(q, s_i)| < c/(m+1)$. Let $s'_0 = s_0$, $s'_{3i-2} = s_{i-1} + d$, $s'_{3i-1} = s_i - d$, and $s'_{3i} = s_i$ for $i = 1, \cdots, m+1$. Then, by (ii), $\sum_t |\varphi| < 3c$ for each refinement t of s', and the theorem is proved.

REMARK. Similar proof shows also that $\sum_t |\varphi|$ has the H-limit 0 at b, a provided $\varphi(r, r-) = \varphi(r+, r) = 0$ for each number r.

THEOREM 3.3 Let $K(r) = \int_0^r E \cdot dF \cdot G$ for each real number r. If a, b is an ordered number pair then $\sum_t |dK - E \cdot dF \cdot G|$ has the H-limit 0 at a, b, where, for $t = \{t_i\}_{i=0}^{n+1}$, $\sum_t |dK - E \cdot dF \cdot G|$ denotes

$$\sum_{i=1}^{n+1} \left| [K(t_i) - K(t_{i-1})] - \frac{E(t_i) + E(t_{i-1})}{2} [F(t_i) - F(t_{i-1})] \frac{G(t_i) + G(t_{i-1})}{2} \right|.$$

REMARK. Similar results hold for $\int_0^r E \cdot G \cdot dF$ and $\int_0^r dF \cdot E \cdot G$.

PROOF. We apply Theorem 3.2 with φ defined by

$$\phi(r, s) = [K(s) - K(r)] - \frac{E(s) + E(r)}{2} [F(s) - F(r)] \frac{G(s) + G(r)}{2}.$$

Condition (i) is easily verified from the definition of the integral. Condition (ii) follows from our discussion of quasi-continuity, with the observation that if $|E(r) - E(s)| < c$ and $|G(r) - G(s)| < c$ for r and s in the interval I then $|\varphi(r, s)| < c(|E|_I + |G|_I) V\{I, F\}$ for r and s in I. This completes our proof.

With K defined as in this theorem, we have two immediate corollaries—the second an application of (2.1):

COROLLARY 3.3a. If each of D and H is a bounded function from the interval $[a, b]$ to B then

$$\int_a^b D \cdot dK \cdot H = \int_a^b D \cdot E \cdot dF \cdot G \cdot H,$$

provided either mean integral exists.

COROLLARY 3.3b. The continuous product ${}_a\prod^b \{1 + E \cdot dF \cdot G\}$ exists and is ${}_a\prod^b \{1 + dK\}$, where, for $t = \{t_i\}_{i=0}^{n+1}$, $\prod_t \{1 + E \cdot dF \cdot G\}$ denotes the product

$$\prod_{i=1}^{n+1} \{1 + \tfrac{1}{4}[E(t_i) + E(t_{i-1})] [F(t_i) - F(t_{i-1})] [G(t_i) + G(t_{i-1})]\}.$$

THEOREM 3.4. Suppose U, V, W is an ordered triple of functions from the real numbers to B, each of which is quasi-continuous and one of which is of bounded variation on each interval, and

$$\begin{aligned} &[U(r) - U(r-)] [V(r) - V(r-)] [W(r) - W(r-)] = 0 \text{ and} \\ &[U(r+) - U(r)] [V(r+) - V(r)] [W(r+) - W(r)] = 0 \text{ for each number } r. \end{aligned} \tag{3.2}$$

If a, b is an ordered number pair then $\sum_t |dU \cdot dV \cdot dW|$ has the H-limit 0 at

a, b, where, for $t = \{t_i\}_{i=0}^{n+1}$, $\sum_t |\, dU \cdot dV \cdot dW \,|$ denotes the sum

$$\sum_{i=1}^{n+1} |\, [U(t_i) - U(t_{i-1})]\,[V(t_i) - V(t_{i-1})]\,[W(t_i) - W(t_{i-1})]\,| .$$

PROOF. Again we apply Theorem 3.2, with φ defined by

$$\varphi(r, s) = [U(s) - U(r)]\,[V(s) - V(r)]\,[W(s) - W(r)].$$

Condition (i) is implied by (3.2), while condition (ii) follows from the bounded variation of one of U, V, and W on each interval and the quasi-continuity of the other two. This completes our proof.

With the observation that

$$\begin{aligned}
&\tfrac{1}{4}[A_2 - A_1]\,[B_2 - B_1]\,[C_2 - C_1] \\
&\qquad = \tfrac{1}{2}[A_2B_2 + A_1B_1]\,[C_2 - C_1] - \tfrac{1}{4}[A_2 + A_1]\,[B_2 + B_1]\,[C_2 - C_1] \\
&\qquad = \tfrac{1}{2}[A_2 - A_1]\,[B_2C_2 + B_1C_1] - \tfrac{1}{4}[A_2 - A_1]\,[B_2 + B_1]\,[C_2 + C_1],
\end{aligned}$$

for A_1, A_2, B_1, B_2, C_1, C_2 all in B, we have two corollaries:

COROLLARY 3.4a. If (3.2) holds with $U, V, W = E, G, F$ then, for each ordered number pair a, b, $\int_a^b EG \cdot dF = \int_a^b E \cdot G \cdot dF$.

COROLLARY 3.4b. If (3.2) holds with $U, V, W = F, E, G$ then, for each ordered number pair a, b, $\int_a^b dF \cdot EG = \int_a^b dF \cdot E \cdot G$.

REMARK. Similar considerations, with $U, V, W = E, F, G$ in (3.2), would show $\int_a^b E \cdot dF \cdot G$ to be the H-limit at a, b of sums of the form

$$\tfrac{1}{2}\sum_{i=1}^{n+1}\{E(t_i)[F(t_i) - F(t_{i-1})]G(t_i) + E(t_{i-1})[F(t_i) - F(t_{i-1})]G(t_{i-1})\},$$

and would give the analogous result for ${}_a\prod^b\{1 + E \cdot dF \cdot G\}$.

As a third application of Theorem 3.4, the identity,

$$\begin{aligned}
&\tfrac{1}{4}[A_2 - A_1]\,[B_2 + B_1]\,[C_2 + C_1] + \tfrac{1}{4}[A_2 + A_1]\,[B_2 - B_1]\,[C_2 + C_1] \\
&\qquad + \tfrac{1}{4}[A_2 + A_1]\,[B_2 + B_1]\,[C_2 - C_1] \\
&\qquad = A_2B_2C_2 - A_1B_1C_1 - \tfrac{1}{4}[A_2 - A_1]\,[B_2 - B_1]\,[C_2 - C_1],
\end{aligned}$$

leads immediately to the corollary:

COROLLARY 3.4c. If (3.2) holds with $U, V, W = E, F, G$ then, for each ordered number pair a, b,

$$\int_a^b dE \cdot F \cdot G + \int_a^b E \cdot dF \cdot G + \int_a^b E \cdot F \cdot dG = E(b)F(b)G(b) - E(a)F(a)G(a).$$

4. *Quasi-harmonic Operators*

The statement that the operator M is *quasi-harmonic*[5] means that M is a function from the ordered real number pairs to B, that for each number t $M(s, t)$

[5] Compare with *harmonic matrices* [10] and *harmonic operators* [6].

is of bounded variation in s on each interval, that for each number s $M(s, t)$ is quasi-continuous in t, and that for each ordered number triple r, s, t $M(r, s)M(s, t) = M(r, t)$ and $M(s, s) = \frac{1}{2}[M(s-, s) + M(s, s-)] = \frac{1}{2}[M(s, s+) + M(s+, s)] = 1$. The identities,

$$\begin{aligned} &[M(s, t) - M(s-, t)]\,[M(t, s) - M(t, s-)] &&= 0, \\ &[M(s+, t) - M(s, t)]\,[M(t, s+) - M(t, s)] &&= 0, \text{ and} \\ &[M(s-, s) - M(s, s-)]^2 = [M(s, s+) - M(s+, s)]^2 &&= 0, \end{aligned} \tag{4.1}$$

for the quasi-harmonic operator M, follow from the definition.

Let QH denote the class of quasi-harmonic operators, and $Q\Phi$ denote the class of functions F from the real numbers to B, of bounded variation on each interval, such that $F(0) = 0$ and for each real number r $[F(r) - F(r-)]^2 = [F(r+) - F(r)]^2 = 0$.

THEOREM 4.1. If F belongs to the class $Q\Phi$ and M is the function defined by

$$M(a, b) = {}_a\prod^b\{1 + dF\} \tag{4.2}$$

for each ordered number pair a, b, then M belongs to QH and for each ordered number pair a, b

$$M(a, b) = 1 + \int_a^b M(a, u)\cdot dF(u), \tag{4.3}$$

$$M(a, b) = 1 + \int_a^b dF(u)\cdot M(u, b), \quad \text{and} \tag{4.4}$$

$$F(b) = \int_0^b M(u, a)\cdot d_u M(a, u). \tag{4.5}$$

PROOF. That M is quasi-harmonic, follows from our remarks at the end of section 2. To establish (4.3), we consider the sequences $F_1, F_2, \cdots$ and $M_1, M_2, \cdots$ introduced in the proof of Theorem 2.4; we note that each M_n is in the class QH. Now, by Theorems 3.2 and 3.5 of [6], (4.3) holds with F_1 and M_1 in place of F and M, respectively. A simple induction argument shows that, for each ordered number pair a, b and each natural number n, $M_n(a, b) = 1 + \int_a^b M_n(a, u)\cdot dF_n(u)$. Since, for each interval I, $V\{I, F_n - F\} \to 0$ and $|M_n(a, b) - M(a, b)| \to 0$ as $n \to \infty$, uniformly for a and b in I, we have (4.3). By Corollaries 3.3a and 3.4a and the first two of identities (4.1), we have

$$\begin{aligned} \int_a^b M(u, c)\cdot d_u M(c, u) &= \int_a^b M(u, c)\cdot M(c, u)\cdot dF(u) \\ &= \int_a^b M(u, c)M(c, u)\cdot dF(u) = F(b) - F(a) \end{aligned}$$

for each number triple a, b, c, and this gives (4.5). Integration by parts then yields

$$F(a) = -\int_0^a d_u M(u, b)\cdot M(b, u), \tag{4.6}$$

for each ordered number pair a, b. By Corollaries 3.3a and 3.4b,

$$\begin{aligned}\int_a^b dF(u)\cdot M(u, b) &= -\int_a^b d_u M(u, b)\cdot M(b, u)\cdot M(u, b)\\ &= -\int_a^b d_u M(u, b)\cdot M(b, u)M(u, b) = M(a, b) - 1\end{aligned} \tag{4.7}$$

for each ordered pair a, b, which gives (4.4) and completes the proof.

THEOREM 4.2. Suppose F belongs to the class $Q\Phi$, M is defined by (4.2), and G is a bounded function from the interval I to B. Then:

(i) if $[G(t) - G(s)] + \int_s^t dF\cdot G = 0$ for s and t in I, then for s and t in I $G(s) = M(s, t)G(t)$.

(ii) if $[G(t) - G(s)] - \int_s^t G\cdot dF = 0$ for s and t in I, then for s and t in I $G(s) = G(t)M(t, s)$.

PROOF. In either case, G is of bounded variation on I. In case (i)—by (4.3) and Corollary 3.3a—

$$\int_s^t M(s, u)\cdot dG(u) = -\int_s^t M(s, u)\cdot dF(u)\cdot G(u) = -\int_s^t dM(s, u)\cdot G(u),$$

while in case (ii)—by (4.4) and Corollary 3.3a—

$$\int_s^t dG(u)\cdot M(u, s) = \int_t^s G(u)\cdot dF(u)\cdot M(u, s) = -\int_s^t G(u)\cdot dM(u, s).$$

In each case, integration by parts completes the proof.

THEOREM 4.3. If M belongs to the class QH and F is defined by (4.6), then F belongs to $Q\Phi$ and M is given by (4.2); there is a one-to-one correspondence, $M \backsim F$, between the classes QH and $Q\Phi$ which is uniquely determined by each of the relations (4.2), $\cdots$, (4.6).

PROOF. Suppose M belongs to QH, and F is defined by (4.6): then F is of bounded variation on each interval, $F(0) = 0$, and

$$\begin{aligned}F(r) - F(r-) &= \tfrac{1}{2}[M(r-, r) - M(r, r-)] \text{ and}\\ F(r+) - F(r) &= \tfrac{1}{2}[M(r, r+) - M(r+, r)],\end{aligned} \tag{4.8}$$

for each number r so that, by (4.1), F belongs to $Q\Phi$ and (4.7) holds as before. The remaining assertions follows from Theorem 4.2 and the proof of Theorem 4.1, and this completes our proof.

REMARK. This correspondence is the natural extension of the correspondence between the classes H and Φ (section 3 of [6]). For M in QH and $M \sim F$, we

supplement the identities (4.1) with

$$
\begin{aligned}
&[M(t, s) - M(t, s-)][F(s) - F(s-)] \\
&\qquad = M(t, s-)[F(s) - F(s-)]^2 = 0, \\
&[M(t, s+) - M(t, s)][F(s+) - F(s)] \\
&\qquad = M(t, s)[F(s+) - F(s)]^2 = 0, \\
&[F(s) - F(s-)][M(s, t) - M(s-, t)] \\
&\qquad = -[F(s) - F(s-)]^2 M(s-, t) = 0, \text{ and} \\
&[F(s+) - F(s)][M(s+, t) - M(s, t)] \\
&\qquad = -[F(s+) - F(s)]^2 M(s, t) = 0.
\end{aligned} \tag{4.9}
$$

THEOREM 4.4. Suppose M belongs to QH and $M \sim F$, G is a function from the real numbers to B of bounded variation on each interval, k is a real number, and Z is an element of B. The only function P from the real numbers to B, bounded on each interval, such that

(i) $P(k) = Z$ and $P(t) - P(s) + \int_s^t dF \cdot P = G(t) - G(s)$ for all s and t, is the P defined by: $P(u) = M(u, k)Z + \int_k^u M(u, v) \cdot dG(v)$.

(ii) $P(k) = Z$ and $P(t) - P(s) - \int_s^t P \cdot dF = G(t) - G(s)$ for all s and t, is the P defined by: $P(u) = ZM(k, u) + \int_k^u dG(v) \cdot M(v, u)$.

PROOF. Using Corollaries 3.3a, 3.4a, and 3.4b as justified by the identities (4.1) and (4.9), we have (with integration by parts)

$$
\begin{aligned}
\int_s^t dF(u) \cdot \left\{ \int_k^u M(u, v) \cdot dG(v) \right\} &= \int_s^t dF(u) \cdot \left\{ M(u, k) \int_k^u M(k, v) \cdot dG(v) \right\} \\
&= \int_s^t dF(u) \cdot M(u, k) \cdot \left\{ \int_k^u M(k, v) \cdot dG(v) \right\} \\
&= -\int_s^t d_u M(u, k) \cdot \left\{ \int_k^u M(k, v) \cdot dG(v) \right\} \\
&= \int_s^t M(u, k) \cdot d \left\{ \int_k^u M(k, v) \cdot dG(v) \right\} + M(s, k) \int_k^s M(k, v) \cdot dG(v) \\
&\qquad - M(t, k) \int_k^t M(k, v) \cdot dG(v) \\
&= \int_s^t M(u, k) \cdot M(k, u) \cdot dG(u) + \int_k^s M(s, v) \cdot dG(v) - \int_k^t M(t, v) \cdot dG(v) \\
&= \int_s^t M(u, k) M(k, u) \cdot dG(u) + \int_k^s M(s, v) \cdot dG(v) - \int_k^t M(t, v) \cdot dG(v)
\end{aligned}
$$

$$= G(t) - G(s) - \left\{\int_k^t M(t, v)\cdot dG(v) - \int_k^s M(s, v)\cdot dG(v)\right\};$$

similarly, we obtain

$$\int_s^t \left\{\int_k^u dG(v)\cdot M(v, u)\right\}\cdot dF(u) = \int_s^t \left\{\int_k^u dG(v)\cdot M(v, k)\right\} M(k, u)\cdot dF(u)$$

$$= \int_s^t \left\{\int_k^u dG(v)\cdot M(v, k)\right\}\cdot M(k, u)\cdot dF(u)$$

$$= \int_s^t \left\{\int_k^u dG(v)\cdot M(v, k)\right\}\cdot d_u M(k, u)$$

$$= \left\{\int_k^t dG(v)\cdot M(v, k)\right\} M(k, t) - \left\{\int_k^s dG(v)\cdot M(v, k)\right\} M(k, s)$$

$$- \int_s^t d\left\{\int_k^u dG(v)\cdot M(v, k)\right\}\cdot M(k, u)$$

$$= \int_k^t dG(v)\cdot M(v, t) - \int_k^s dG(v)\cdot M(v, s) - \int_s^t dG(u)\cdot M(u, k)\cdot M(k, u)$$

$$= \int_k^t dG(v)\cdot M(v, t) - \int_k^s dG(v)\cdot M(v, s) - \int_s^t dG(u)\cdot M(u, k) M(k, u)$$

$$= \left\{\int_k^t dG(v)\cdot M(v, t) - \int_k^s dG(v)\cdot M(v, s)\right\} - [G(t) - G(s)].$$

The proof is completed by application of Theorems 4.1 and 4.2.

THEOREM 4.5. Suppose each of M_1 and M_2 belongs to QH and $M_1 \sim F_1$, $M_2 \sim F_2$, G is a function from the real numbers to B of bounded variation on each interval, k is a real number, and Z is an element of B. If the condition (3.2) of Theorem 3.4 holds with U, V, W, the ordered triple F_1, G, F_2, then the only function P from the real numbers to B, bounded on each interval, such that

$$P(t) = \int_k^t P\cdot dF_2 - \int_k^t dF_1\cdot P + [G(t) - G(k)] + Z \tag{4.10}$$

for all t, is the function P defined by

$$P(u) = M_1(u, k)\{Z + \int_k^u M_1(k, v)\cdot dG(v)\cdot M_2(v, k)\} M_2(k, u)\,. \tag{4.11}$$

PROOF. First, suppose P is defined by (4.11), and let H be defined by: $H(u) = Z + \int_k^u M_1(k, v)\cdot dG(v)\cdot M_2(v, k)$. By application of Corollaries 3.4a, 3.4b, 3.4c, and 3.3a, we have for each number t

$$\int_k^t P\cdot dF_2 - \int_k^t dF_1\cdot P$$

$$= \int_k^t M_1(u, k)\cdot H(u)\cdot dM_2(k, u) + \int_k^t dM_1(u, k)\cdot H(u)\cdot M_2(k, u)$$

$$= P(t) - Z - \int_k^t M_1(u, k) \cdot dH(u) \cdot M_2(k, u)$$

$$= P(t) - Z - \int_k^t M_1(u, k) \cdot M_1(k, u) \cdot dG(u) \cdot M_2(u, k) \cdot M_2(k, u)$$

$$= P(t) - Z - [G(t) - G(k)] ,$$

so that (4.10) holds; here, we have used the fact {deduced from (4.8)} that condition (3.2) holds with U, V, W the triple $M_1(u, k), H(u), M_2(k, u)$. If, now, we suppose that P is bounded on each interval and (4.10) holds, then P is of bounded variation on each interval; moreover, since each of F_1 and F_2 is in the class $Q\Phi$, it follows that (3.2) holds with U, V, W the triple F_1, P, F_2. The representation (4.11) is then obtained by application of Theorem 4.4, and the proof is complete.

REMARK 1. The preceding theorem is a proper extension of Lemma 1 of [6] (section 4), since if F_1 and F_2 are continuous then M_1 and M_2 are harmonic and all the mean integrals involved can be replaced by Stieltjes integrals—the condition on F_1, G, F_2 is then automatically satisfied.

REMARK 2. Suppose the function F belongs to the class $Q\Phi$, and suppose that $F(a)F(b) = F(b)F(a)$ for each pair a, b of numbers. Then, using Corollaries 3.3a and 3.4a with a simple induction argument, we find that for each number r and each natural number n

$$\int_0^r [F(u)]^n \cdot dF(u) = \frac{[F(r)]^{n+1}}{n+1} .$$

By Theorems 4.1 and 4.2, it follows that $\prod_s^t \{1 + dF\} = \operatorname{Exp}\{F(t) - F(s)\}$ for all numbers s and t.

5. *Continuous Continued Fractions*

We are now concerned with the product space $S \times S$ and the corresponding space B^2 of continuous linear transformations; we identify B^2 as the class of 2×2 matrices of elements of B, and we suppose the norm on $S \times S$ so chosen that if T is in B^2 then

$$(5.1) \qquad |T_{ij}| \leq |T| \leq |T_{11}| + |T_{12}| + |T_{21}| + |T_{22}| \qquad \text{for } i, j = 1, 2.$$

Let $Q\Phi^2$ and QH^2 denote the classes of functions into B^2 corresponding, respectively, to the classes $Q\Phi$ and QH of functions into B. We use I to denote the identity transformation in $S \times S$.

Suppose F is a function from the real numbers to B^2. If $s = \{s_i\}_{i=0}^{n+1}$ is a monotone number sequence, we define

$$(5.2) \qquad M_s(F) = \begin{pmatrix} A_s(F) & B_s(F) \\ C_s(F) & D_s(F) \end{pmatrix} = \prod_{i=1}^{2n+2} \begin{pmatrix} X_i & 1 + Y_i \\ 1 & 0 \end{pmatrix},$$

where (for $i = 1, \cdots, n + 1$)

$$(5.3) \qquad \begin{pmatrix} Y_{2i-1} & X_{2i-1} \\ X_{2i} & Y_{2i} \end{pmatrix} = \begin{pmatrix} F_{11}(s_i) - F_{11}(s_{i-1}) & F_{12}(s_i) - F_{12}(s_{i-1}) \\ F_{21}(s_i) - F_{21}(s_{i-1}) & F_{22}(s_i) - F_{22}(s_{i-1}) \end{pmatrix},$$

and, if Z is an element of B, then

$$K_s\{F, Z\} = [A_s(F)Z + B_s(F)][C_s(F)Z + D_s(F)]^{-1}, \tag{5.4}$$

whenever $[C_s(F)Z + D_s(F)]^{-1}$ belongs to B; we see from (5.2) that $K_s\{F, Z\}$ may be represented symbolically as the continued fraction[6]

$$K_s\{F, Z\} = X_1 + (1 + Y_1)\frac{1}{X_2 + \cdots + (1 + Y_{2n+1})\dfrac{1}{X_{2n+2} + (1 + Y_{2n+2})\dfrac{1}{Z}}}, \tag{5.5}$$

i.e., as the composite of linear fractional transformations

$$T_i(U) = [X_iU + (1 + Y_i)][U]^{-1} \qquad (i = 1, \cdots, 2n + 2). \tag{5.6}$$

If a, b is an ordered number pair, the H-limit at a, b of $K_s\{F, Z\}$ is the *continuous continued fraction* ${}_aK^b\{F, Z\}$.

THEOREM 5.1. Suppose the function F, from the real numbers to B^2, is of bounded variation on each interval, $M(a, b) = {}_a\prod^b\{I + dF\}$ for each ordered number pair a, b, and

$$\begin{aligned}[F_{12}(r) - F_{12}(r-)][F_{21}(r) - F_{21}(r-)] &= [F_{12}(r+) - F_{12}(r)][F_{21}(r+) - F_{21}(r)] \\ &= [F_{12}(r) - F_{12}(r-)][F_{22}(r) - F_{22}(r-)] \\ &= [F_{12}(r+) - F_{12}(r)][F_{22}(r+) - F_{22}(r)] = 0\end{aligned} \tag{5.7}$$

for each number r. If a, b is an ordered number pair, then $M(a, b)$ is the H-limit at a, b of $M_s(F)$.

PROOF. By Theorem 3.2, it follows from (5.7) that each of $\sum_s |dF_{12}\cdot dF_{21}|$ and $\sum_s |dF_{12}\cdot dF_{22}|$ has the H-limit 0 at a, b. With the observation that $M_s(F)$ has the form

$$\prod_{i=1}^{n+1}\left\{I + [F(s_i) - F(s_{i-1})] + \begin{pmatrix} X_{2i-1}X_{2i} & X_{2i-1}Y_{2i} \\ 0 & 0 \end{pmatrix}\right\}, \tag{5.8}$$

the result then follows by Theorem 2.4 and the inequality (2.1).

REMARK. In case F is continuous, it follows from Theorem 2.1 that $\mathbf{M}(a, b)$ is the limit of $M_s(F)$ in the same sense in which it is the limit of $\prod_s\{I + dF\}$.

THEOREM 5.2. In addition to the suppositions of the preceding theorem, suppose F belongs to the class $Q\Phi^2$, so that M is in QH^2. If b is a number at which

[6] Compare with (4.14) of [6], where $F_{11} = F_{22} = 0$.

each of F_{21} and F_{22} is continuous and Z is in B, there is a segment J containing b such that if t is in J then

$$(5.9) \qquad {}_tK^b\{F, Z\} = [M_{11}(t, b)Z + M_{12}(t, b)][M_{21}(t, b)Z + M_{22}(t, b)]^{-1}.$$

Proof is omitted since this follows directly from Theorem 5.1, together with the representation (4.3) for $M(a, b)$, by applying Lemma 3 of [6] (section 4).

THEOREM 5.3. Suppose F belongs to $Q\Phi^2$, each of F_{21} and F_{22} is continuous, Z is in B, and b is a number. There exists a segment J containing b such that the only bounded function P from J to B such that, for t in J,

$$(5.10) \qquad P(t) = Z + \int_t^b dF_{12} + \int_t^b dF_{11}\cdot P - \int_t^b P\cdot dF_{22} - \int_t^b P\cdot dF_{21}\cdot P,$$

is the function P given by: $P(t) = {}_tK^b\{F, Z\}$ for t in J.

PROOF. Our proof follows closely our previous proof for the case that F is continuous (Theorem 4.1 of [6]). We note that our assumptions here imply the suppositions of Theorems 5.1 and 5.2; also we have, from (4.3), for all t

$$(5.11) \qquad \begin{cases} L(t) = Z + \int_t^b dF_{11}\cdot L + \int_t^b dF_{12}\cdot R \text{ and} \\ R(t) = 1 + \int_t^b dF_{21}\cdot L + \int_t^b dF_{22}\cdot R, \end{cases}$$

where $L(t) = M_{11}(t, b)Z + M_{12}(t, b)$ and $R(t) = M_{21}(t, b)Z + M_{22}(t, b)$. Since R is continuous, there is a segment J containing b such that the function N, $N(t) = [R(t)]^{-1}$, is continuous from J to B and is of bounded variation on each subinterval of J. Let $P(t) = L(t)N(t)$ for t in J; P is quasi-continuous and bounded. By appropriate use of Corollaries 3.3a, 3.4a, and 3.4b, we have for t in J:

$$\int_t^b R\cdot dN = -\int_t^b dR\cdot N = \int_t^b dF_{11}\cdot L\cdot N + \int_t^b dF_{22}\cdot R\cdot N$$

$$= \int_t^b dF_{21}\cdot P + \int_t^b dF_{22}, \text{ and}$$

$$\int_t^b P\cdot dF_{21}\cdot P + \int_t^b P\cdot dF_{22} = \int_t^b P\cdot R\cdot dN = \int_t^b L\cdot dN$$

$$= Z - P(t) - \int_t^b dL\cdot N$$

$$= Z - P(t) + \int_t^b dF_{11}\cdot L\cdot N + \int_t^b dF_{12}\cdot R\cdot N,$$

from which (5.10) follows. Suppose, now, that P_1 and P_2 are solutions of (5.10) for t in some interval J containing b, and let $P = P_1 - P_2$. Then we find that P is of bounded variations on each subinterval of J and, for t in J,

$$(5.12) \qquad P(t) = \int_b^t P\cdot dF_2 - \int_b^t dF_1\cdot P,$$

where we define

$$(5.13)\qquad \begin{cases} F_1(t) = F_{11}(t) - \tfrac{1}{2}\int_b^t \{P_1 + P_2\}\cdot dF_{21} \text{ and} \\ F_2(t) = F_{22}(t) + \tfrac{1}{2}\int_b^t dF_{21}\cdot\{P_1 + P_2\} \end{cases}$$

Now F_2 is continuous and, from the fact that F belongs to $Q\Phi^2$, it is readily seen that Theorem 4.5 is applicable to show that $P(t) = 0$ for t in J. This completes our proof.

REMARK. Analogues of the two preceding theorems hold with only an assumption of "one-sided" continuity at the number b. Also, Theorem 2.6 provides an extension of Theorem 5.2 to the limiting case of ${}_1K^{+\infty}\{F, Z\}$ for t sufficiently large.

6. *An Example*

Let $a_1, a_2, \cdots$ and $b_1, b_2, \cdots$ be sequences of elements of B, and f and g be step functions defined as follows:

$$(6.1)\qquad f(r) = \sum a_n \text{ for } n < r, \qquad g(r) = \sum b_n \text{ for } n + 1 \leq r,$$

with $f(r) = 0$ if $r \leq 1$ and $g(r) = 0$ if $r < 2$; now, let

$$(6.2)\qquad F(r) = \begin{pmatrix} 0 & f(r) \\ g(r) & 0 \end{pmatrix} \qquad \text{for each number } r.$$

Then F belongs to the class $Q\Phi^2$, and the hypothesis of Theorem 5.1 holds. Moreover, we have the continuous product and continuous continued fraction formulas (for $n = 1, 2, \cdots$),

$$(6.3)\qquad {}_1\prod^{n+1}\{I + dF\} = {}_{i=1}\prod^{n}\left\{\begin{pmatrix} a_i & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} b_i & 1 \\ 1 & 0 \end{pmatrix}\right\},$$

and

$$(6.4)\qquad {}_1K^{n+1}\{F, Z\} = a_1 + \cfrac{1}{b_1 + \cfrac{1}{a_2 + \cfrac{1}{b_2 + \cdots + \cfrac{1}{a_n + \cfrac{1}{b_n + \cfrac{1}{Z}}}}}},$$

for all Z in B for which the latter has meaning.

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A SURVEY OF NORTH CAROLINA SHRIMP NURSERY GROUNDS

BY AUSTIN B. WILLIAMS

University of North Carolina Institute of Fisheries Research, Morehead City, North Carolina

INTRODUCTION.—North Carolina estuaries which serve as shrimp nursery grounds are located at, or near, the northern limit of the breeding ranges for three penaeid shrimps, *Penaeus setiferus* (Linnaeus), *P. duorarum* Burkenroad and *P. aztecus* Ives. This geographic position, and the fact that these estuaries are among the most extensive on the southeastern coast of the United States, have given impetus to an investigation aimed at determining the relationships of juvenile shrimp populations to the fisheries for adults. It has been shown (Williams, 1955) that the species composition and the concentration of juveniles are not uniform in the estuaries. Adult populations also display this lack of uniformity, and these phenomena are manifest along the entire southeastern coast of the United States. With the information now available, the differences in population density and species composition among juveniles can be discussed in detail.

METHODS.—The extent of the nursery areas is shown in Figure 1. Localities along the coast were selected for sampling in places which were easily accessible by road and which contained a variety of ecological situations (Williams, *l. c.*). At these localities a varying number of stations was established. The most concentrated work was done in Carteret and Onslow Counties where six localities were sampled repeatedly for two successive years and five others for one year. Two localities in Pamlico and Hyde Counties were sampled once a month for two successive springs and summers; and others in Brunswick, Onslow, Pamlico,

FIG. 1. Map of the eastern 21 counties in North Carolina showing four generally distinctive shrimp nursery areas. Named from lower left to upper right they are: Brunswick-Onslow Area; Carteret-Onslow Area; West Pamlico Sound Area; North Pamlico Sound Area.

Beaufort, Hyde and Dare Counties were sampled once a month, or sporadically, for one spring and summer.

The gear for collecting (Williams, *l.c.*) consisted of a beam trawl 4 ft. wide equipped with a ¼ in. bar measure net. The trawl was pulled with a skiff powered by an outboard motor. Over half of the localities were composed of stations which had a measured tow length of 200 yards. The remainder of the localities had stations at which the tow lengths were an estimated 200 yards. Such tows were obviously subject to error, but in general they slightly exceeded the chosen standard.

PHYSICAL CONDITIONS.—Observed physical conditions vary widely among the localities sampled. The salinity range extends from nearly fresh water to 37‰, but the lower salinities are almost invariably found upstream in tidal creeks. Generally, the landward sides of Pamlico Sound have lower salinities than localities nearer the ocean (Roelofs and Bumpus, 1953).

The influence of periodic tides varies in the different estuaries. Daily tidal fluctuations are greatest in Brunswick County (4 ft.) and somewhat less to the northeastward (Bogue Inlet 2.2 ft., Beaufort Inlet 2.5 ft., Ocracoke Inlet 1.9

ft., Hatteras Inlet 2.0 ft., Oregon Inlet 1.8 ft., U.S.C. & G.S., 1954). Tidal currents are readily observed in estuaries from Brunswick County through the seaward side of Carteret County and in the immediate vicinity of the inlets to Pamlico Sound through the barrier islands. However, along the landward side of Pamlico Sound there are no perceptible periodic tides, although even light winds have an effect on the water level (Roeolfs and Bumpus, 1953). The swiftest tidal currents occur in the Brunswick County area and elsewhere in shallow tidal creeks and in the vicinity of inlets. Currents along the landward sides of Pamlico Sound are usually barely perceptible and to a great extent are dependent on the water level of the sound, this in turn depending on the wind direction and force. Runoff currents occur in the tributaries in times of heavy rain.

Water depth in the nursery areas for the youngest shrimps seldom exceeds 10 ft. and is usually less than six feet. Some of the nursery areas are nearly laid bare at low tide.

Temperatures vary widely in such shallow areas. A maximum range of 4°C. to 35°C. has been recorded (1951–54), and juveniles have been collected at both extremes of temperature.

A most critical factor in distribution of the young is the nature of the bottom. Hard clay and sand, shell bar, shifting sand, soft mud and peat bottoms are all found in various parts of the estuaries; often a number of these types occur at a single locality, but the stations with soft bottom and a cover of debris have the largest populations of juveniles.

DISCUSSION.—Results of the survey show that there are four areas which are generally distinctive in the structure of their juvenile shrimp populations. For the sake of distinction they can be named as follows (Fig. 1): (1) the *Brunswick-Onslow Area* which includes estuaries extending from the South Carolina line northeastward to a point between New River Inlet and Bogue Inlet; (2) the *Carteret-Onslow Area* which extends from south of Bogue Inlet northeastward through most of the Carteret County estuaries; (3) the *West Pamlico Sound Area* which extends from portions of northern Carteret County estuaries through those of Pamlico, Beaufort and Hyde Counties almost to Engelhard in Hyde County; (4) the *North Pamlico Sound Area* which extends from south of Engelhard in Hyde County through Dare County to the vicinity around Roanoke Island. The extent of nursery grounds inside the barrier islands between the vicinity south of Ocracoke Inlet and Oregon Inlet is practically unknown. Two collections made near Cape Hatteras in summer, 1954, showed a population structure most like that of the Carteret-Onslow Area. Beds of aquatic vegetation are known to occur on shoals between Carteret County and Ocracoke Inlet. Beyond that point, and especially between Hatteras Inlet and Oregon Inlet, these beds are sparse and small. This expanse of shoals is often exposed to severe wave action, and that may account for the sparse vegetation. The lack of cover, except in protected coves, indicates that this area is not a major shrimp nursery.

In all these areas the specific population structure changes from season to season (Williams, *l. c.*). Generally a nursery area is utilized by a single species at a time, although there is some overlap. The population structure of the named

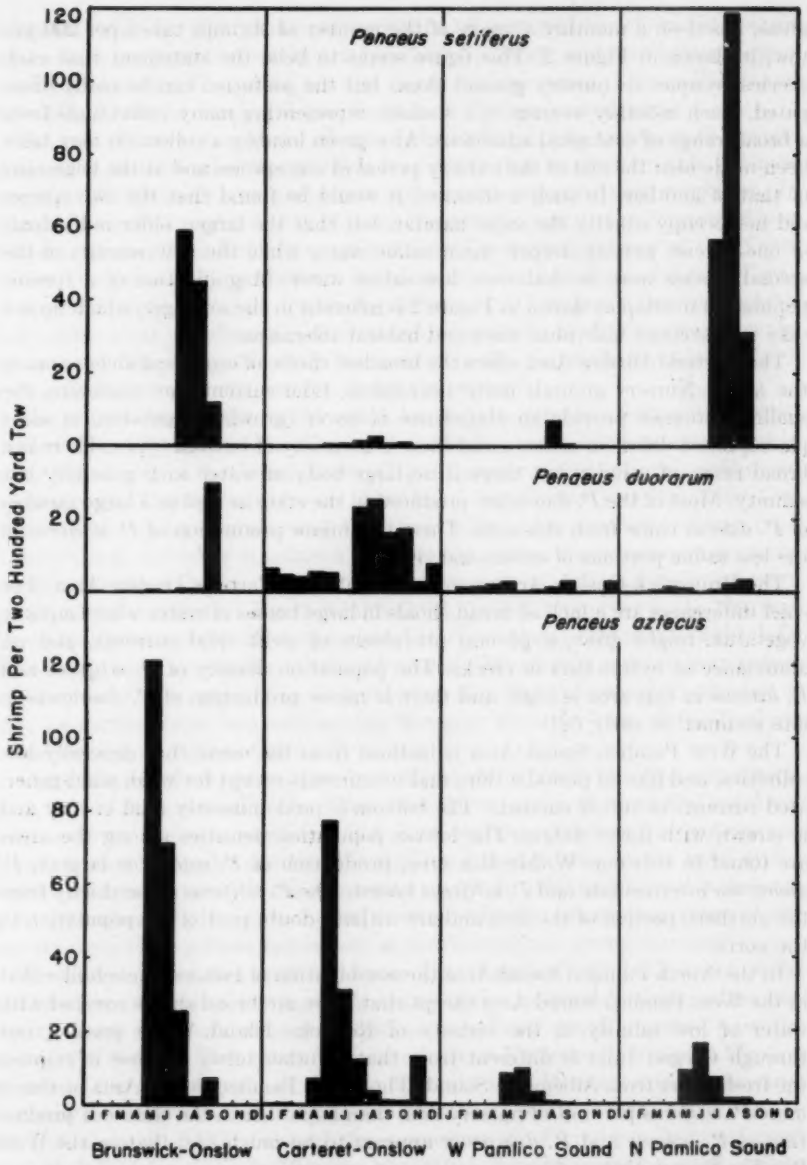

FIG. 2. Juvenile population densities of three species of shrimps in four nursery areas. Densities are shown as monthly averages of shrimps collected per 200 yard tow with a 4 ft. beam trawl equipped with a ¼ inch bar mesh bag.

areas, based on a monthly average of the number of shrimps taken per 200 yd. tow, is shown in Figure 2. This figure seems to belie the statement that each species occupies its nursery ground alone, but the confusion can be easily dissipated. Each monthly average is a statistic representing many individuals from a broad range of ecological situations. At a given locality a collection may have been made near the end of the nursery period of one species and at the beginning of that of another. In such a situation it would be found that the two species did not occupy exactly the same habitat, but that the larger, older individuals of one species were in deeper, more saline water while the new recruits of the second species were in shallower, less saline water. Magnification of a specific population overlap as shown in Figure 2 is inherent in the averages, which do not take into account individual sizes and habitat tolerances.

The Carteret-Onslow Area offers the broadest choice of ecological niches among the areas. Nursery grounds occur near inlets, tidal currents are moderate, the shallow estuaries provide an abundance of cover (growing vegetation in some places, forest debris in others), and there is a variety of bottom types. There is a broad range of salinity but there is no large body of water with generally low salinity. Most of the *P. duorarum* produced in the state as well as a large number of *P. aztecus* come from this area. There is a minor production of *P. setiferus* in the less saline portions of creeks and rivers.

The Brunswick-Onslow Area is somewhat like the Carteret-Onslow Area. The chief differences are a lack of broad shoals in large bodies of water where aquatic vegetation might grow, a general prevalence of swift tidal currents, and an abundance of oyster bars in creeks. The population density of *P. setiferus* and *P. aztecus* in this area is high, and there is minor production of *P. duorarum* in late summer or early fall.

The West Pamlico Sound Area is farthest from the ocean, has generally low salinities, and has no periodic tides and no currents except for weak wind-generated currents or runoff currents. The bottom is predominantly mud or clay and is strewn with forest debris. The lowest population densities among the areas are found in this one. Within this area, production of *P. aztecus* is largest, *P. duorarum* intermediate and *P. setiferus* lowest. The *P. setiferus* come chiefly from the northern portion of the area and are without doubt part of the population to the north.

In the North Pamlico Sound Area the combination of factors is much like that in the West Pamlico Sound Area except that there are broad shoals covered with water of low salinity in the vicinity of Roanoke Island. Water passing out through Oregon Inlet is different from that in other inlets because it empties the fresh water from Albemarle Sound. The North Pamlico Sound Area produces more *P. setiferus* per unit of nursery area than any other in the state but production of *P. aztecus* and *P. duorarum* appears to be much like that in the West Pamlico Sound Area.

Reasons for the distinctiveness of shrimp populations in these areas are not known because the requirements of juvenile shrimps are not known, except for a few generalities; hence, the statements that follow must be judged in the light of

available evidence. The young are known to be attracted to soft muddy places where there is adequate cover, either vegetation or debris, and such bottoms occur in all of the areas. The young are also known to seek areas of low salinity, and such places exist in varying degree in each of the four named areas.

The role of currents and the effects of channeling in the transport of recruits is not fully understood although there is evidence that recruits are able to travel considerable distances where channels and currents may aid their migration. In Carteret County a segment of the Inland Waterway connects the Newport River, an estuary near Beaufort Inlet, with Adams Creek, a tributary of the Neuse River. The distance by water from Beaufort Inlet to the mouth of Adams Creek is approximately 18 miles. Under the influence of Beaufort Inlet, perceptible daily tides occur in Adams Creek although winds have modifying effects on the water level. No perceptible daily tides occur in the Neuse River. Adams Creek appears to serve as a channel for shrimp migration.

The juvenile population in this creek has definite affinities with the Carteret-Onslow Area. Within a radius of approximately five miles, shrimp populations in other tributaries of the Neuse River (Fig. 1) appear to be variously influenced by this creek. Downstream, South River has a low-density population like that of the West Pamlico Sound Area. Only four miles across the Neuse River from Adams Creek are other tributaries that are also rather low producers of young shrimp. Clubfoot Creek, upstream from the mouth of Adams Creek, is hydrographically somewhat similar to Adams Creek for it is connected to the Newport River by the narrow, shallow, abandoned Harlowe Canal. There is a slight daily tidal flow in this canal that is modified by winds. The shrimp population structure in Clubfoot Creek appears to be somewhat like that in Adams Creek; but it may be derived from two sources, the Newport River by way of the Harlowe Canal, and from Adams Creek.

Unfortunately there are no other known systems in North Carolina comparable with that of Adams Creek. The White Oak River, in the Carteret-Onslow Area, may serve as a poor comparison, but in it, shrimps occur as far upstream as brackish water extends, and the distance from Bogue Inlet to the head of the brackish water varies with the amount of runoff. In 1952 and 1953 this distance was approximately 15 miles. Again, currents and the channeling effect of the stream seem to be influencing factors in distributing the young shrimps.

The lowest population densities are in West Pamlico Sound. This area is the farthest from the ocean, has generally low salinities, no periodic tides and no currents, except for weak wind-generated or occasional runoff currents near the shore. The distance from either Ocracoke Inlet or Hatteras Inlet across Pamlico Sound to the nearest point of shore is approximately 20 miles, nearly the same distance as from Beaufort Inlet to the mouth of Adams Creek, yet along the western shore of Pamlico Sound the concentration of young is low compared with that in Adams Creek. This low population density might be attributed to the distances from the inlets, and to the lack of currents and channels to help transport recruits.

The fact that larval stages are able to migrate from the open sea to shore

with no channels to guide them, and with feeble currents at best to help transport them, seems to negate the argument that the larger post-larvae would use such aids to find suitable nursery ground. The fact remains that almost all of the dense populations of juveniles are found in areas where there is perceptible current and tide. An exception to this occurrence is the large *P. setiferus* nursery in the North Pamlico Sound Area. *Penaeus setiferus* young seem to seek, or tolerate, lower salinities than young of the other two species. Oregon Inlet, which is near this nursery ground, differs somewhat from the other inlets in that a large volume of brackish water is discharged through it, freshened by Albermarle Sound and its tributaries. Much of the area in the vicinity of Roanoke Island is shoal. In such an area where salinity is low at the inlet, where broad shoals preserve weak currents, and where an abundance of muddy bottom is available, the tendency for the young to follow channels or moderate currents may not be so great as in more saline deeper areas.

It is instructive to examine the relationships between the juvenile populations and the adult populations and hence with the shrimp fisheries. The fishery for *P. duorarum* is centered in the southern part of Pamlico Sound, Neuse River, Core, Back and Bogue Sounds, and in the ocean between Beaufort Inlet and Bogue Inlet. This area is chiefly within the Carteret-Onslow Area where most of the *P. duorarum* juveniles are produced. The fishery for *P. setiferus* is split. There is usually a fishery in northern Pamlico Sound and another in the Cape Fear region. At certain times of year, chiefly in the fall, *P. setiferus* is caught in oceanic waters between these areas. It appears that the adults in this case also tend to concentrate in waters adjacent to their nursery areas. The fishery for *P. aztecus* centers in Pamlico Sound. This occurrence differs from the other fisheries in that adults are not found in abundance in waters adjacent to the most densely populated nursery areas. No facts are available for an explanation of this phenomenon. The low-density population of juveniles could remain in Pamlico Sound during the warm months, making no effort to migrate to sea, and thus remain more available for catch than in areas to the south where they might migrate rapidly from the small estuaries to sea. An alternative explanation is that the young may migrate from the densely populated nursery areas north to Pamlico Sound and remain there through the summer. Tagging experiments have not been attempted to find the source of these adults.

SUMMARY.—The penaeid shrimp nursery grounds in North Carolina can be divided into four areas on the basis of juvenile population densities and specific composition. In general, the highest concentration of juveniles occurs in the shallow portions of estuaries from Brunswick County northeastward through the seaward side of Carteret County, and in the shoal parts of northern Pamlico Sound. The role of channels and tidal currents in concentrating populations is considered. With one exception, sparse populations occur in regions of weak current and no perceptible tide. The fisheries for adult *P. duorarum* and *P. setiferus* may occur near the nursery grounds for the species. The relationship of the adult *P. aztecus* population to its nursery ground is obscure.

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LOCAL VARIATION AND RELATIONSHIPS OF THE CYPRINODONT FISH, *FUNDULUS RATHBUNI* JORDAN AND MEEK

BY JERRAM L. BROWN

Department of Conservation, Cornell University, Ithaca, New York

Fundulus rathbuni is a small species found thus far only in the Piedmont region of North Carolina. Jordan and Evermann (1896a) made *F. rathbuni* the type of a new subgenus, *Gambusinus*, a category which has not been particularly useful, and the phylogenetic relationships of the species have never been clearly apparent from the literature. The form is of interest from an evolutionary standpoint since for its small range it shows a remarkable amount of geographic variability, more so than in any other *Fundulus* studied.

The author is indebted to the collectors of the specimens employed in this study, which are housed in the Cornell University fish collection. My thanks also go to Dr. Edward C. Raney, under whom the work was done as part of a review of the genus *Fundulus* completed and used as a Master's thesis at Cornell University in 1954.

METHODS.—Dorsal, anal, and pectoral rays were counted at their bases. The last two rays of the dorsal and anal were never counted as one, as has been the custom in counting some species. Lateral line scales were counted according to the method of Hubbs and Lagler (1949: 11) except that the most anterior scale counted was the one in which the center of the exposed field of the scale lay exactly on or just posterior to a vertical line through the upper extremity of the gill slit. For pectoral rays and lateral line scales the counts of the left and right sides were added together; where only one side could be counted, the count was doubled. Scales around the caudal peduncle (usually, but not necessarily, the least count) were counted vertically at a point halfway between the posterior base of the dorsal and anal fins and the anterior limits of the upper and lower procurrent caudal rays. Scales around the body were counted in a complete ring encircling the body halfway between the anus and pelvic fin bases, and immediately anterior to the dorsal fin. When the scale immediately anterior to the dorsal origin was abnormal, the next normal scale row was used.

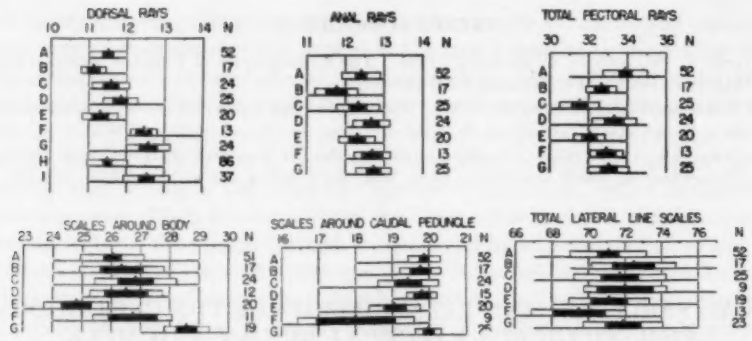
DORSAL RAYS
10 11 12 13 14 N
ANAL RAYS
11 12 13 14 N
TOTAL PECTORAL RAYS
30 32 34 36 N
SCALES AROUND BODY
23 24 25 26 27 28 29 30 N
SCALES AROUND CAUDAL PEDUNCLE
16 17 18 19 20 21 N
TOTAL LATERAL LINE SCALES
66 68 70 72 74 76 N

FIG. 1. Roanoke R.: *A*. Sugartree Cr.—Cape Fear R.: *B*. Upper Haw R., *C*. South Buffalo Cr., *D*. Morgan's Cr., *E*. Deep R.—Pee Dee R.: *F*. Wilkes Co., *G*. Davidson Co.—*H*. Total Cape Fear R.—*I*. Total Pee Dee R.

EXPLANATION OF FIGURE.—In the figure the range is shown as a single, heavy, horizontal line; the mean, by a short, pointed, vertical line; one standard deviation on either side of the mean, by a hollow bar; and two standard errors on either side of the mean, by a solid black bar. Regardless of sample size the denominator used in calculating the standard deviation was always "N-1". In general, for normal distributions when the black bars for two samples do not overlap, it is safe to conclude that the difference between the two means is probably not due to chance. Because the distributions only approach normal, statistical interpretations should be made on the conservative side. When the hollow bars do not overlap, an approximate separation of specimens of 84% or greater is indicated. Hubbs and Hubbs (1953) give details for interpreting this type of diagram.

SYNONYMY

Fundulus rathbuni Jordan and Meek, *in* Jordan, 1889: 351, pl. 44, fig. 7; Reedy Fork and other tributaries of Cape Fear River, N. C.; Yadkin River, N. C. (original description). Jordan, 1890: 98, 133–134 (ecological data to accompany original description; additional localities). Garman, 1895: 107, pl. 2, fig. 9 (description; suggests close relationship to *heteroclitus*; teeth figured). Jordan and Evermann, 1896a: 633, 635, 649 (type of new subgenus *Gambusinus*; in key; description; Type, *U.S.N.M. 39860*); 1896b: 311 (compiled); 1900: 3255, pl. 105, fig. 280 (same plate as in original description). Smith, 1907: 149 (figure; description). Pratt, 1923: 101, 102 (in key; brief description). Brimley and Mabee, 1925: 16 (Upper Little River, Cape Fear system). Jordan, 1929: 101 ("streams of Va. and E.N.C."). Fowler, 1945: 34, 125, fig. 176 (in table by river systems; two records and partial synonymy; figure).

Zygonectes rathbuni, Jordan, Evermann, and Clark, 1930: 175, 179 (type of subgenus *Gambusinus*; range). Schrenkeisen, 1938: 182 (compiled).

DISCUSSION.—An examination of the figures or tables shows that each of the seven collections examined differs significantly from two or more of the others in at least three of the six meristic characters used. The only character which shows relative consistency within a river system is the dorsal ray count. Table 1

TABLE I

Frequency distributions of dorsal, anal, and pectoral ray counts in Fundulus rathbuni

Locality	Number of Dorsal Rays				N	M	s	2sM
	11	12	13	14				
Roanoke	26	26	—	—	52	11.50	.50	.14
Cape Fear								
Upper Haw R.	15	2	—	—	17	11.12	.33	.16
S. Buffalo Cr.	10	14	—	—	24	11.58	.49	.21
Morgan's Cr.	5	19	1	—	25	11.84	.46	.19
Deep R.	14	6	—	—	20	11.30	.47	.21
Pee Dee								
Wilkes Co.	—	8	4	1	13	12.46	.35	.19
Davidson Co.	1	8	15	—	24	12.58	.58	.24
Total Cape Fear	44	41	1	—	86	11.50	.53	.11
Total Pee Dee	1	16	19	1	37	12.54	.61	.20

	Number of Anal Rays			N	M	s	2sM
	11	12	13				
Roanoke	—	31	21	52	12.40	.50	.14
Cape Fear							
Upper Haw R.	5	11	1	17	11.76	.56	.27
S. Buffalo Cr.	1	15	9	25	12.32	.56	.22
Morgan's Cr.	—	8	16	24	12.67	.48	.20
Deep R.	—	14	6	20	12.30	.47	.21
Pee Dee							
Wilkes Co.	—	4	9	13	12.69	.48	.27
Davidson Co.	—	7	18	25	12.72	.46	.18

	Pectoral Rays (both sides)							N	M	s	2sM
	30	31	32	33	34	35	36				
Roanoke	1	1	8	2	33	2	6	52	33.87	1.16	.32
Cape Fear											
Upper Haw R.	—	—	9	5	3	—	—	17	32.65	.79	.38
S. Buffalo Cr.	6	2	16	0	1	—	—	25	31.52	1.01	.40
Morgan's Cr.	1	0	6	1	15	1	—	24	33.33	1.18	.48
Deep R.	1	1	16	0	2	—	—	20	32.05	.83	.37
Pee Dee											
Wilkes Co.	—	—	5	4	4	—	—	13	32.92	.86	.48
Davidson Co.	—	—	11	4	8	2	—	25	33.04	1.06	.42

shows the means for the Roanoke and all the Cape Fear collections to approximate 11.5 while the means for the two Pee Dee collections approximate 12.5. A line drawn between 12 and 13 dorsal rays separates 99% of the 86 Cape Fear specimens from 54% of the 37 Pee Dee specimens; average separation 76.44%; coefficient of divergence* 0.92. None of the other characters shows any con-

* For methods of calculation and interpretation see Mayr, Linsley and Usinger (1953: 146).

TABLE II

Frequency distribution of scale counts in Fundulus rathbuni

Locality	Lateral Line Scales (both sides)												N	M	s	2sM
	66	67	68	69	70	71	72	73	74	75	76	77				
Roanoke	—	2	4	4	10	12	10	5	1	2	1	1	52	71.08	2.10	.32
Cape Fear																
Upper Haw R.	—	—	—	1	2	5	2	1	2	2	1	1	17	72.47	2.32	1.13
S. Buffalo Cr.	—	1	1	5	1	3	5	2	3	2	2	—	25	71.72	2.54	1.02
Morgan's Cr.	—	—	—	—	3	1	3	0	1	0	0	1	9	72.00	2.29	1.53
Deep R.	—	—	1	3	5	5	1	0	2	1	1	—	19	71.11	2.18	1.00
Pee Dee																
Wilkes Co.	2	2	1	2	0	3	2	0	1	—	—	—	13	69.46	2.57	1.43
Davidson Co.	—	1	0	3	2	3	6	1	5	1	1	—	23	71.87	2.22	.97

	Scales Around Caudal Peduncle						N	M	s	2sM
	16	17	18	19	20	21				
Roanoke	—	—	2	3	47	—	52	19.87	.44	.12
Cape Fear										
Upper Haw R.	—	—	1	2	14	—	17	19.76	.56	.27
S. Buffalo Cr.	—	1	2	7	14	—	24	19.42	.83	.35
Morgan's Cr.	—	—	—	3	12	—	15	19.80	.41	.21
Deep R.	—	1	1	14	4	—	20	19.05	.69	.31
Pee Dee										
Wilkes Co.	2	2	1	2	2	—	9	18.00	1.58	1.05
Davidson Co.	—	—	—	2	22	1	25	19.96	.35	.14

	Scales Around Body Before Anus								N	M	s	2sM
	23	24	25	26	27	28	29	30				
Roanoke	—	3	11	26	6	3	2	—	51	26.02	1.09	.30
Cape Fear												
Upper Haw R.	—	1	5	3	5	1	2	—	17	26.35	1.46	.71
S. Buffalo Cr.	—	2	1	7	6	5	3	—	24	26.83	1.40	.60
Morgan's Cr.	—	—	3	4	1	4	—	—	12	26.50	1.24	.36
Deep R.	2	7	5	5	1	—	—	—	20	24.80	1.11	.49
Pee Dee												
Wilkes Co.	—	1	1	2	3	4	—	—	11	26.73	1.35	.81
Davidson Co.	—	—	—	—	1	8	8	2	19	28.58	.77	.35

sistent separation between the two systems; and it is possible that because of the unusual variation among local populations analyses of additional populations would reveal the above collections to be inadequately representative of their respective river systems.

In the three scale counts employed, the upstream (Wilkes Co.) collection of the Pee Dee is consistently and significantly lower than the downstream (Davidson Co.) one. Further samples from other populations in the Pee Dee system will be necessary to confirm the consistency of these differences.

Both Pee Dee samples are distinguished from the others by their higher dorsal ray counts; an analysis of the variations in the remaining five collections from the Roanoke and Cape Fear systems follows. Taken separately, the Roanoke, South Buffalo Creek, and Morgan's Creek samples are not significantly different in means from all others in any character. The upper Haw River and Deep River samples are significantly different from all others in anal rays and scales around the body respectively. Although the percentage separation of specimens is low, the differences between means are statistically significant. A more detailed examination of the interrelationships of local populations of *Fundulus rathbuni* is needed; particularly interesting would be the discovery of correlations between the scale and ray counts and the local environmental conditions. Are these variations the result of chance acting in small populations, or are they the product of the population gene pools interacting with slightly different environments?

The relationships of *Fundulus rathbuni* to the other species of the genus are somewhat perplexing. Because of its similarities with *F. stellifer* in (1) coloration of the young, (2) the position of the dorsal fin in relation to the anal fin, and (3) ecological requirements, it would appear to belong in the subgenus *Xenisma* Jordan. However, the possibility of an independent origin and of convergence in the development of these characters in response to similar ecological conditions cannot be completely rejected. *F. rathbuni* is a more robust species than *stellifer* or *catenatus* and does not have the same adult body form, coloration, or extreme development of fins. In *rathbuni* the pectoral and pelvic fins are not as pointed nor as long, the dorsal and anal fins have 2 to 6 fewer rays, and the lateral line scale count is lower than that of typical *Xenisma*.

Garman (1895: 107) states with reference to *rathbuni*: "Form intermediate between that of *catenatus* and that of *heteroclitus*, with nearer approach to the latter." "If it were not for the six branchiostegal rays, in most cases, it would be difficult to find reasons for separating this species from *F. heteroclitus*; to which it would bear much the same relationship as exists between the brown spotted and the silver flecked individuals of *F. grandis*." He was correct in suggesting its similarity in meristic characters to the subgenus *Fundulus*, but the extremely developed anal pouch in *heteroclitus* belies its closeness to *rathbuni*. The condition of the pouch in *F. confluentus* (which Garman confounded with *grandis*) is the same as that of *rathbuni* and its meristic characters are similar also.

Probably because of the position of the dorsal fin, which is very slightly before the anal fin in *rathbuni* instead of very slightly behind it, as in *Xenisma*, Jordan

and Evermann (1896a: 633, 649) erected the subgenus *Gambusinus*, with *rathbuni* as its type species. They say: "This species and the four which follow seem to be entirely intermediate between the typical species of *Fundulus* and the species called *Zygonectes*. Their presence makes it apparently impossible to maintain *Zygonectes* as a distinct genus, notwithstanding the great difference between such species as *F. dispar* and *F. majalis*." They also included in *Gambusinus* the following: *F. lineatus* (a synonym of *sciadicus* and entirely unrelated to *rathbuni*), *F. albolineatus* (probably intermediate in its characters between *rathbuni* and typical *Xenisma*), *F. confluentus* (a species belonging to the subgenus *Fundulus*, but similar in meristic characters to *rathbuni*), and *F. funduloides* (apparently a synonym of *F. pulvereus*). Jordan, Evermann, and Clark (1930: 179) maintained *Gambusinus* but included in it only *rathbuni* and *Z. extensus* (synonym of *diaphanus*, Hubbs, 1931). This leaves *rathbuni* in a monotypic subgenus which, in my opinion, should be synonymized with *Xenisma*.

The range includes the Piedmont region of North Carolina in the Roanoke, Cape Fear, and Pee Dee systems.* It was recorded by Jordan (1890) from the following localities in the Cape Fear System: Reedy Fork, Allemance Creek, Buffalo Creek, and other tributaries of the Cape Fear near Greensboro; and also in the Yadkin System: Jumping Run, Little Yadkin or South River, Second Creek. Recorded by Brimley and Mabee (1925) from the Upper Little River, Cape Fear System. Recorded by Fowler (1945) from Crane Creek and South River.

MATERIAL EXAMINED

Roanoke R., N. C.—Person Co.: trib. Sugartree Cr., 6 mi. e. of Leesburg, Rt. 158, *CU 11958*, 52 specimens (standard lengths 23–62 mm.).

Cape Fear R., N. C.—Guilford Co.: Haw R., 3.5 mi. s. of Stokesdale, Rt. 68, CU uncatalogued, 16 (30–55); trib. S. Buffalo Cr., 5 mi. sw. of Greensboro, *CU 3536*, 25 (25–52). Alamance Co.: Haw R. at Altamaha, Rt. 87, CU uncatalogued, 1 (30). Orange Co.: Morgan's Cr. at Mason's Farm, 1 mi. below Chapel Hill, *CU 14093*, 25 (19–54). Randolph Co.: trib. Deep R., ¼ mi. w. of Chatham Co. line, Rt. 64, *CU 10076*, 20 (29–55).

Pee Dee R., N. C.—Wilkes Co.: trib. Yadkin R., 1.2 mi. w. of Moravian Falls, Rt. 180, *CU 11488*, 13 (22–55). Davidson Co.: Gobbles Cr., 2 mi. s. of Yadkin R., Rt. 64, *CU 19319*, 25 (25–57).

SUMMARY.—For *Fundulus rathbuni*, a little known cyprinodont species, found only in the Piedmont region of North Carolina, all known literature references are presented together with a statement of range as far as known from published information and from specimens in the Cornell University fish collection. An unexpectedly large amount of morphological variation among local populations at a level below that of conventional subspecific recognition is demonstrated. It is recommended that the relationships of *Fundulus rathbuni* to *F. stellifer* and *F. catenatus* be recognized by synonymyzing the subgenus *Gambusinus* under the subgenus *Xenisma*.

* Miller (1955, Occ. Papers Mus. Zool. Univ. Mich., No. 568: 9) records *Fundulus rathbuni* from the Neuse River System on the basis of a recently acquired and uncatalogued collection in the University of Michigan Museum of Zoology (*in litt.*).

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ANOTHER MYCOTYPHA

BY FREDERICK A. WOLF

Department of Botany, Duke University, Durham, North Carolina

Several years ago, Fenner (1932) described as a new genus of the Mucoraceae of the tribe Cephalideae, a fungus that appeared as a contaminant in cultures made from tissues of decaying oranges. She designated it *Mycotypha* because its

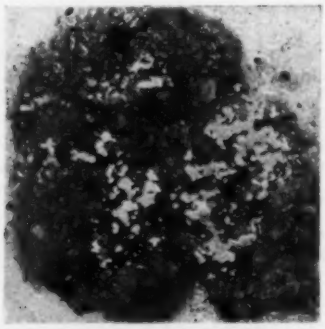

FIG. 1. Whitish cushions on sand, aggregates of young sporangiophores of *Mycotypha dichotoma*, natural size.

diminutive fructifications resembled those of the well-known aquatic plant called cat-tail or Typha. The specific name, *microspora*, was given because the sporangia were very small, being 2 to 4 μ in diameter. So far as the writer has been able to determine, mycologists have never encountered this peculiar fungus subsequently. During the past winter, however, an organism tentatively identified as *Mycotypha microspora* was observed in fruiting stage on the surface of slash pine seed, *Pinus elliottii* Engelm., being germinated in sand in flats, in the greenhouse. But on further study it proved to be specifically distinct and, therefore, will be described herein as another monosporangiate *Mycotypha*.

DESCRIPTION OF THE FUNGUS.—This fungus is believed to have been brought into the greenhouse with the seed of slash pine for the following reasons: (1) A portion of these slash pine seed were treated with a commercial disinfectant while the remainder were left untreated. The fungus appeared only on the untreated seed. (2) It did not appear on either similarly treated or untreated seed of loblolly pine, *Pinus taeda* L., or of longleaf pine, *P. palustris* Mill., planted in the same flats. (3) The sand in which seed of each of these species was sown came from the same source, hence it seems improbable that the sand constituted the source of inoculum. However, the fungus fruited abundantly on the surface of the sand near the slash pine seed soon after it was first seen, and after several weeks it fruited also on the "wings" of longleaf pine seed and on the surface of loblolly pine seed. Eventually it spread and fruited on the moist walls of the flats immediately above the soil level. Here it formed brown encrustations 10 to 20 cm. in length and approximately 1 cm. in width.

As this fungus appears in nature, in fruiting stage, on pine seed, it differs from all other Mucorales in that it forms circular, compact but not sclerotioid cushions or encrustations (Fig. 1) each having a diameter of 1 to 3 mm. These little cushions are pure white early in the morning, but a few hours later they become fawn-colored, and by afternoon are distinctly rusty brown to dark brown. These color changes are associated with the development and maturation of the closely-standing sporangiophores which densely cover the entire upper surface of the cushions. The upper extremities of these sporangiophores constitute the

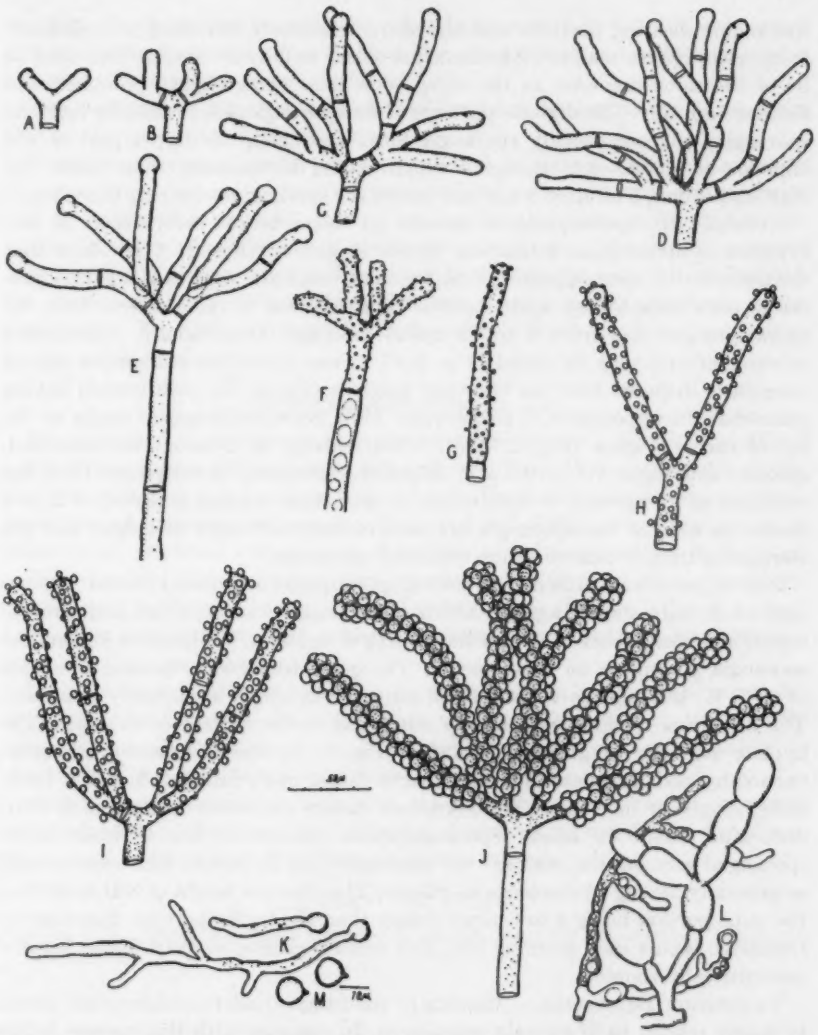

FIG. 2. Stages in the development of *M. dichotoma*. All, except M, drawn to same scale. A. Bifurcate tip of young sporangiophore. B–E. Further bifurcation, elongation, and septation of the tips of sporangiophores. These portions become sporangium-bearing. F. Formation of sterigmata. G. Tip of sporangiophore which failed to branch. The bulbous tips of the sterigmata are young sporangia. H, I. Stages in sporangium formation. J. Mature sporangiophore bearing numerous, globular sporangia. K. Germinating sporangia. L. Portion of mycelium. M. One-spored sporangia, (drawn to the near-by scale).

sporangium-bearing portions and are characteristically branched in a dichotomous and digitate manner. The branches stand well apart distally and tend to be of the same diameter as the stipe, sometimes being slightly knobbed and flattened apically. The digitate portions of the sporangiophore normally bear the sporangia, but occasionally sporangia form also along the upper part of the stipe or on unbranched elements which extend horizontally from below the digitate portion. The stipe is septate, as are the sporangium-bearing branches.

Normally the sporangiophore attains its entire height before there is any evidence of sporangium formation. Stages in growth (Fig. 2, A–E) show that the apex of the sporangiophore first becomes bifurcate and, as elongation proceeds, each branch may again become bifurcate one or more times. Soon the sporangiophore has from 2 to 16 apical branches. Occasionally, unbranched sporangiophores may be noted (Fig. 2, G). Then thorn-like sterigmata appear irregularly disposed over the branched portions (Fig. 2, F), each branch having somewhat the appearance of an Hercules' club. Soon bulbs appear singly at the tip of each sterigma (Fig. 2, G-J), which enlarge to become the one-celled, globular sporangia, 7.5 to 9.6 μ in diameter. Sporangial development from the initiation of sterigmata to maturation of sporangia requires a period of 2 to 4 hours. As soon as the sporangia are mature they are easily dislodged and the sterigmata usually adhere to the detached sporangia.

Pure cultures were obtained by sowing sporangia on acidulated potato dextrose agar or on Sabourand's agar to which small amounts of penicillin and streptomycin had been added to inhibit the growth of bacteria. Within 6 to 8 hours the sporangia germinate on these media. The germ tubes soon become branched (Fig. 2, K) but septa are not formed until the hypha is abundantly branched. The mycelium remains very closely adpressed to the surface of the agar. The hyphae are very irregular in diameter (Fig. 2, L) and are densely granular, vacuolate, and guttulate. In old cultures large, oval, inflated elements form, either singly or in chains. The mycelium covers the entire surface of a Petri dish after about 72 hours. Sporangiophores mature within 48 hours after sporangial germination, and are not aggregated, as in nature, but occur singly, as generally among Mucoraceae in culture. They have a height of 800 to 1000 μ, the stipe portion being 4 to 6 times longer than the fertile portion. Sporangium formation occurs each morning and, as a result, cultures on Petri dishes become concentrically zonate.

TAXONOMIC DISCUSSION.—Manifestly the fungus under consideration herein is closely related to *Mycotypha microspora*. In common with this species, it has the following structural features: (1) The one-spored sporangia are borne similarly on the surface of elongated capitella. However, the capitella are not inflated, nor are the sporangia arranged in a dextrorse spiral but appear to lack a definite pattern of arrangement. (2) The young mycelium is similarly coenocytic, and similarly becomes septate with age. But even after septations arise, the mycelial elements (cells) in each species are multinucleate. This conclusion rests upon the fact that each capitellar, sporangiophore-element of each species bears many sporangia. (3) The digitate, multicephalous sporangiophore of the fungus under

consideration is homologous with the inflated sporangiophore tip of *M. microspora* and with monocephalous globular, head-like, sporangiophore tips of such related genera as *Choanephora* and *Blakeslea*.

The diameter of the sporangia of this fungus is approximately three times that of the sporangia of *M. microspora*.

Even though zygospores have not been found, in spite of numerous attempts to induce their formation, this fungus is believed to be among the Mucoraceae and to belong to *Mycotypha*. It may be recalled that Fenner (1932) also was unable to secure zygospores of *M. microspora* in cultures. The fungus discussed herein is clearly distinct from that described by Fenner. Since its sporangiophores are characteristically dichotomous, the new specific name, *dichotoma*, seems appropriate. The following brief Latin description is a summary of the salient features of *M. dichotoma*.

Mycotypha dichotoma sp. nov.

Efformantibus pulvinulis vel crustis a superficie seminis folliculis *Pini elliottii* atque arenae in qua semina germinant, 1–3 mm. diam. Primo pulvinulis albidis, tunc ferrugineis, deinde brunneis v. atro-fuscis. Hyphae fertiles dense gregariae a superficie pulvinulorum sed sparsae in culturis 800–1000 μ altae, septatae, 1–8-dichotomae, interdum non-ramosae. Capitella cylindrica, non-inflata, in longitudine variable, sine sporangiis plus minusve 150–250 x 12–15 μ. Sporangiis primo hyalinis, demum brunneolo-atrofuscis, multis, globosis, 7.5–9.6 μ diam. 1-sporis, in maturitate caducis, in brevis sterigmatibus ferentibus. Sterigmatibus saepe ad sporangia adhaerentibus.

In cultis, mycelia sterilia hyalina, irregulariter atque laxe ramosa, prostrata, irregulariter in diametro, dense granulosa ac guttulata, primo continua sed in aetate septata. Zygosporae ignotae. Hab. ad semina *Pini elliottii* atque speciorum aliorum Pini, in Carolina septentrionale.

SUMMARY.—This account deals with the morphology of a fungus occurring on germinating seed of slash pine. It is a monosporagiate member of the Mucoraceae, and is designated *Mycotypha dichotoma* sp. nov.

LITERATURE CITED

FENNER, E. A. 1932. *Mycotypha microspora*, a new genus of the Mucoraceae. Mycologia **24**: 187–198.

NORTH AMERICAN LEJEUNEACEAE
III. PARADOXAE: COLOLEJEUNEA, SECTIO MINUTISSIMAE

BY RUDOLF M. SCHUSTER[1]

Department of Botany, Duke University, Durham, North Carolina

COLOLEJEUNEA (SPRUCE) SCHIFFN., EMEND. EVS.

Lejeunea subg. *Cololejeunea* Spruce, Trans. Proc. Bot. Soc. Edinburgh **15**: 291, 1884.
Cololejeunea subg. *Physocolea* Schiffn., Nat. Pfl.-Fam. **1**(3): 122, 1895.
Cololejeunea Evans, Bull. Torrey Bot. Club **38**: 251, 1911.
Physocolea Stephani, Sp. Hep. **5**: 863, 1916.

Plants in *decumbent to appressed green to yellowish-green patches*; shoots slender and fragile, usually 250–800 (1000–1400) μ wide with leaves; *stems with 5 rows of cortical cells, a single row of medullary cells*, delicate, 25–60 μ thick usually. Rhizoids singly or in a small tuft from near base of *each* leaf. Leaves distant to approximate, rarely subimbricate, spreading at an angle of 40–75 degrees from stem, varying from narrowly lanceolate to broadly ovate, attached to stems by an exceedingly *short, nearly transverse line*; lobes with cells often produced as conical tubercles; leaf-margins usually crenulate or denticulate due to projecting cells. Lobules variable: varying from *ca.* ⅘ the size of the lobe or obsolete and reduced to the elongated apical tooth, rarely reduced to a 1–2-celled basal fold; when typically developed, lobule distinctly inflated; apex of lobule bearing a 1–2 (3–4)-celled apical tooth, at the *proximal base* of which occurs the hyaline papilla (which is usually slightly entally displaced),[2] and proximad of this a single proximal tooth, formed commonly of a single cell (rarely 2 or several proximal teeth present); *sinus between distal and proximal teeth usually relatively broad and distinct*. Cells thin-walled and delicate, occasionally with small trigones and intermediate thickenings, the walls pellucid, colorless; ocelli absent (our species) or present, but not forming a basal vitta; oil-bodies small, typically 2–10 per cell, *ca.* 2–3 x 4–6 μ or smaller, either distinctly segmented or finely papillose. *Underleaves totally lacking*. Asexual reproduction by discoid "gemmae" (brood-bodies) which originate *from the surfaces* (rarely *also marginal cells*) of the lobes; "gemmae" usually 16–22-celled, bearing 3 or 4 marginal swollen (slime) cells that serve as organs of attachment, or 16–36-celled and without marginal slime cells.

Usually autoecious, rarely (in extra-territorial species) dioecious. Female inflorescence on a more or less elongated branch, subtended by 1–2 innovations. Bracts similar to leaves, but less spreading, often smaller (with narrower and shorter lobes; lobules flat with apices modified). Perianth typically obovoid, abruptly narrowed into a distinct if short beak, rarely erostrate, *typically not compressed, usually erect, 5-carinate at least on distal fourth* (the keels, and often the intervening cells, more or less tuberculate in most species). Male inflorescences with bracts bearing lobules that are larger and more inflated than lobules of leaves; antheridia 1 or 2 per bract. Capsule spherical; seta of 2 concentric cell-layers, the inner of 4 cell rows, the outer of 12 cell rows.

TYPE: *Lejeunea calcarea* Lib. (= *Cololejeunea calcarea* (Lib.) Spr.), a frequent species of western Europe, closely related to *C. biddlecomiae*.

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[2] In species with reduced lobules, the hyaline papilla is commonly terminal, or inserted slightly proximad of the apex of the apical tooth.

The genus *Cololejeunea* is a large and poorly understood genus. Any estimate of the number of known species is meaningless since the only listing of all the species (excepting recently described ones) by Stephani is an uncritical compilation of species which belong in part in *Leptocolea*, in part in *Aphanolejeunea*. There appears to be a rather high level of endemism, or at least there has been free production of sibling species in geographically relatively recently isolated areas. As a consequence, the taxonomic problems in this group are immense. They are compounded by the entirely artificial basis on which *Cololejeunea* is separated from the genus *Leptocolea*.

The species of *Cololejeunea* are mostly delicate. Ours range largely from 360 μ to 850 μ in width, although certain tropical species are 1–1.4 mm. wide or more (Jones, 1954); by contrast, those of *Leptocolea* are often more robust. The species are almost without exception pioneers, either on bare rocks, or more commonly on the bark of trees, or on living leaves. They are usually plants of relatively humid and shaded areas, although certain of them (among ours *C. minutissima*, *C. biddlecomiae*) may undergo ecesis under relatively xeric conditions. In our region the majority of species occur on bark, more rarely on rocks, although in Florida several species (*C. diaphana*, *C. subcristata*, *C. tuberculata*, *C. ornata*) are not infrequently found creeping over the leaves of higher plants, among them often those of ferns, such as species of the filmy ferns, *Trichomanis*, or of larger ferns, such as the halberd ferns, *Tectaria*. However, they may also occur on the leaves of various angiosperms, among them the fronds of palms (*Sabal palmetto*, etc.), and rarely the evergreen leaves of dicotyledonous trees and shrubs. Such epiphyllous occurrences are the rule, rather than the exception, in the wetter tropical forests (Jones, 1954).

Cololejeunea has been variously defined in recent years. Some workers (Macvicar, 1926; Frye and Clark, 1947) would include *Aphanolejeunea* within it, others have regarded it as generically distinct. Recently Zwickel has split off those species with a line of basal ocelli, whose walls are more or less sharply thickened, as *Taeniolejeunea*. It is probable that further generic segregates will be split off from the genus as it stands. For the American student, the sole immediate problem is whether to accept *Aphanolejeunea* at all. As is stated under the latter, the claims for its recognition are not very strong. However, in all species of the genus that the writer has studied, he has found marginal gemmae oriented at right angles to the leaf-surface, while in *Cololejeunea* the gemmae are usually intramarginal in origin and lie parallel to the leaf-surface. Evans (1911, 279–285), in an otherwise admirable discussion of the gemmae of the complex, fails to note this important difference. Indeed, he emphasizes that in *Cololejeunea*, *Aphanolejeunea*, and *Leptocolea* the gemmae "differ primarily from the gemmae of *Cyclolejeunea* in being borne on the surface of the lobes instead of on the margin." *Cyclolejeunea*, as is well-known, bears marginal discoid gemmae, marginally attached. In the present complex the gemmae, whether marginal or of surface origin, are never marginally attached, but excentrically so. Marginal gemmae have been noted not only for *A. evansii* and *ephemeroides* by the author, but also in *A. teotonii* (Allorge et Jovet-Ast, 1950) and *A. longifolia* (Jovet-Ast,

1947). For some time it was believed that the marginal restriction of gemmae in *Aphanolejeunea* could serve as a generic character, separating the group from *Cololejeunea*. However, recently it has been possible to demonstrate the free development of marginal gemmae in *C. minutissima* (*RMS 31480*) and in *C. diaphana*. Intramarginal cells may also be involved in gemmae-initiation in both of these species, unlike *Aphanolejeunea*, where intramarginal cells have not been found to function as gemmae-initials. This difference in the origin of the gemmae, together with the more strongly marked heterophylly and the differences in lobule-form (emphasized in the key) are here deemed sufficient for maintaining the two genera as distinct.

Evans (1911, 1938) has been instrumental in clearing the nomenclatorial confusion which this group has undergone. Stephani (1915), under the invalid name *Physocolea*, listed 119 species of the genus. At least 20 are estimated to have been described since. The segregation of *Taeniolejeunea*, which includes only a few species, has not greatly affected this total. Of these species, a rather large number may prove synonyms. However, the minute size of many species suggests that there may still be a considerable number of undescribed ones. The most recent thorough survey of the nearctic species is that by Evans (1938).

The relatively few (9) nearctic species are quite well marked, offering no major systematic problems. Our species, here placed in three sections, represent the more unspecialized species of the genus. They lack all markedly derivative features, such as (1) ocelli; (2) dentate or hyaline-margined leaves; (3) horned or otherwise produced, or armed, keels of the perianth; (4) highly derivative lobules; and (5) a tendency for the perianth to be distinctly flattened.

Recently E. W. Jones (1953, 1953a, 1954) has devoted considerable attention to the African species of the *Cololejeunea-Leptocolea* complex. He has re-emphasized the fact that the separation of the complex, into two genera, "by the character of the perianth . . . seems to be largely artificial; even typical species of *Leptocolea* such as *L. crenatiflora* may have the perianths with a low but sharp dorsal keel, and with distinct ventral keels when young, and conversely many species here classed as *Cololejeunea* have perianths which are either more or less compressed, especially when young, or which are plane and unkeeled dorsally and inflated and scarcely keeled ventrally. So far as there is any distinctive feature in the *Leptocolea* perianth, it lies in the presence of broad lateral wings rather than in compression or in the absence of a dorsal keel." The writer is thoroughly in sympathy with the conclusions advanced by Jones. On the basis of the perianth, our regional *Leptocolea cardiocarpa*, therefore, would fall more nearly into *Cololejeunea, sensu* Jones. The extraordinary similarity between juvenile *L. cardiocarpa* and *C. subcristata* also suggests a close affinity between those species, traditionally classed in *Leptocolea*, which bear merely compressed perianths, and more typical species of *Cololejeunea*. The conclusion is therefore inescapable that the genera *Leptocolea* and *Cololejeunea* are mere "form" genera. A more natural division into genera—perhaps better into a multiplicity of subgenera—must await a monograph of all known species.

The recent splitting-off of some species by Benedix, as *Pedinolejeunea*, has

served to define *Cololejeunea* somewhat more narrowly. It will surely be necessary also to split off such divergent taxa as *Cololejeunea cornuta* E. W. Jones (1954, p. 436, fig. 13), in which the perianth is produced upward as four discrete, compressed horns, and in which the lobules are quite anomalous.

In an important work on "Indomalayische Cololejeuneen" Benedix (Feddes Repertorium **134:** 1–88, 31 pls., 1953) has divided *Cololejeunea* into six subgenera: (1) *Taeniolejeunea*, differing from the other subgenera in the presence of a vitta formed of ocelli; (2) *Metalejeunea*, lacking ocelli, but with the leaf-margins bordered by hyaline cells; (3) *Lasiolejeunea*, lacking ocelli and hyaline marginal cells, but with cells sharply conoidally produced; (4) *Chondriolejeunea*, differing in the foliaceous stylus (based on a single species from New Guinea); (5) *Cryptolejeunea*, differing in the strongly involute, ciliate or entire, free margin of the lobule; (6) *Chlorolejeunea*, characterized by flat lobe and lobule, and densely chlorophyllose cells. The writer, to date, knows this work only through a review in the *Revue Bryologique et Lichenologique* (1954). Benedix's subgenera do not cover all of the extreme types in the genus, with the consequence that the establishment of additional intrageneric groups can scarcely be avoided.

In the classification of the species of this genus, the form and position of the gemmae play an important rôle. In the majority of our species the discoid gemmae are relatively simply organized, without the angular protrusion of the marginal cells, and without the development of tumid, opaque, slime-cells ("organs of attachment"). In these species, furthermore, there is usually considerable variation in the number of cells of which the gemmae are composed (see discussion in conjunction with *C. minutissima myriocarpa*). The species of this complex also are relatively unspecialized in that the gemmae are usually not sharply restricted in occurrence. For instance, in the *C. minutissima-myriocarpa* complex and in *C. contractiloba*, the gemmae originate almost indiscriminately from both antical and postical faces of the lobes, as well as occasionally from the outer margins of the marginal cells (in which case they lie perpendicular to the lobe). However, in some species of this complex the gemmae become sharply restricted in occurrence. In *C. biddlecomiae*, for instance, they are always restricted to the intramarginal cells, and to the postical faces of the lobes. In the sparse specimens of *C. setiloba* seen, the gemmae are restricted to the antical faces of the lobes. In the gemmae-form, and the postical restriction of them, *C. biddlecomiae* very closely approaches *Leptocolea cardiocarpa*.

By contrast, in two of our species (*C. tuberculata* and *C. diaphana*), the gemmae are specialized in form: they are 16–22-celled, with the marginal cells in part sharply angularly produced, and with 2–3 of the marginal cells swollen, opaque, serving as "organs of attachment" during the germination of the gemmae. The redrawing of the gemma of *C. tuberculata* in Frye and Clark (1947, p. 874) fails to show the two swollen cells, although Evans (1915) clearly indicated their presence, for the mature gemma at least. Identical gemmae occur in *Aphanolejeunea*, a genus bearing extremely close affinities to such species of *Cololejeunea* as *C. diaphana*.

In addition to the gemmae, the ability (or inability) of the cells of the leaves to

develop conoidal excrescences, or "tubercles" is of marked systematic importance. In a variety of species (such as *C. minutissima*, *C. setiloba*, *C. subcristata*) the cells of the leaves are convex, but the walls never produced outward as specialized protrusions. In the majority of our species, each cell of the lobe (less often only occasional cells) is sharply conically elevated centrally, on the abaxial face of the cell, resulting, in the aggregate, in a leaf with a very greatly roughened texture. The degree to which these tubercles are developed is a variable (with environmental conditions) within the species, and is also variable from one species to the next (i.e. genetically controlled). In three of our species (*C. contractiloba*, *C. ornata*, *C. tuberculata*) the tubercles are produced over the whole face of the lobe, and are extremely salient, with the tip of each tubercle prominently thick-walled; in the latter two of these three species, such a tuberculate extension of each cell also characterizes the cells of the lobules. By contrast, in *C. diaphana* and *C. biddlecomiae*, the degree of development of the tubercles is always less marked. In *C. diaphana*, indeed, extreme shade forms may show almost no trace of tubercles. A similar situation, to a lesser extent, characterizes occasional extremes of *C. biddlecomiae*. Inversely, "normal" phases of these two species, from more or less xeric environments, show quite marked conical extension of the cells of the lobe (but not of the lobule).

Utilizing as primary bases the gemmae and leaf cells, our species of *Cololejeunea* can be arranged in three distinct sections, as by the following conspectus. *C. ornata* and *C. macounii* are omitted, gemmae being unknown in these species. The former belongs almost surely in the Calcareae, the latter probably in the Sectio Denticulatae (together with the east Asiatic *C. denticulata*).

CONSPECTUS OF SPECIES AND SECTIONS

1. Gemmae evenly rounded, the cells not saliently protuberant marginally, without trace of organs of attachment ..... 2.
   2. Leaves rounded or obtuse at apex, their cells nontuberculate. Sectio MINUTISSIMAE 3.
      3. Leaves ovate, tapering from apical fourth to narrowly rounded apex; lobules reduced in size: length less than half that of lobe ..... 4.
         4. Lobules, at least in large part, inflated, with tooth near apex 2-celled; gemmae 16-celled ..... *C. subcristata*
         4. Lobules reduced to a vestigial basal fold bearing an apical tooth (2) 3–4 cells long; gemmae 16–22 celled ..... *C. setiloba*
      3. Leaves broadly ovate-rotundate, less than 1.3 × as long as wide; lobules *ca.* 0.75 × length of lobe (but sometimes a mere narrow, erect flap) ..... 5.
         5. Gemmae of an indeterminate cell number, up to 26–34-celled. *C. minutissima* subsp. *minutissima*
         5. Gemmae of ± determinate cell number, 14–16-celled, usually. *C. minutissima* subsp. *myriocarpa*
   2. Leaves acute or subacute, ovate-lanceolate, tuberculate ..... Sectio CALCAREAE 6.
      6. Gemmae of *ca.* 20 cells, produced from antical and postical faces of lobes, and sometimes from marginal cells; stylus obsolete ..... *C. contractiloba*
      6. Gemmae of 26–34 cells at maturity, indeterminate in cell number, restricted in development to postical face of lobe; stylus filiform, prominent ..... *C. biddlecomiae*
1. Gemmae with margins irregular, some (or all) cells angularly produced; 3–4 gibbous "slime" cells developed; gemmae 16–22-celled; leaves markedly heterophyllous: many lobules vestigial; leaves at least slightly tuberculate; stylus vestigial.

Sectio DIAPHANAE 7.

7. Lobules (when inflated) with cells tuberculate-produced; dorsal lobes broadly ovate-pointed, very sharply tuberculate-echinulate; gemmae usually 16-celled. *C. tuberculata*

7. Lobules (when inflated) with cells smooth; dorsal lobes lanceolate or ovate-lanceolate, quite narrow, obsoletely to rather moderately tuberculate....8.

8. Gemmae usually 20–22-celled; leaves virtually smooth to weakly tuberculate. *C. diaphana*, typical

8. Gemmae usually 16-celled; leaves moderately and conspicuously tuberculate over entire face of lobe....*C. diaphana cristulata*

KEY TO SPECIES

1. Stylus distinct, usually over 5 cells long, prominent; dorsal leaf-surface tuberculate throughout; lobule *ca.* 0.5 × length of dorsal lobe, when well-developed; not tropical.2.

2. Ventral (external) surface of lobule smooth, the cells not tuberculate; styli simple, the cells smooth; lobules usually all normally developed; lobes up to 350–400 μ long. *C. biddlecomiae*

2. Ventral surface of lobule with the cells tuberculate; styli often with the cells conically protuberant, appearing dentate; lobules usually largely obsolete; lobes attaining a maximum length of 180–200 μ....*C. ornata*

1. Stylus obsolete, 1–2-celled or reduced to an ephemeral papilla; tropical and subtropical, only on Coastal Plain (except *C. macounii*)....3.

3. Lobes at apex more or less sharply pointed, ovate-pointed to lanceolate in shape; lobules often strongly dimorphic; always with some lobules obsolete (sometimes with the majority or all obsolete); dorsal lobe with cells (or at least a few of them) tuberculate-produced, sometimes only very weakly so....4.

4. Ventral surface of the lobules (which are most often well-developed) strongly tuberculate; apical tooth of lobule 2 cells long; perianth beakless....*C. tuberculata*

4. Ventral surface of lobules (when well-developed) smooth; often with obsolete lobules; perianth beaked....5.

5. Apical tooth of inflated lobules small, 1-celled, not lying in plane of lobule (but postically displaced); dorsal surface of lobes always strongly tuberculate throughout; gemmae without organs of attachment, lacking angular protuberances....*C. contractiloba*

5. Apical tooth of inflated lobules large, 2-celled, lying in plane of lobule; lobes either weakly tuberculate, and only locally so, or moderately tuberculate, the tubercles low, their tips little thickened; gemmae with organs of attachment and 4–6 angularly protuberant marginal cells....6.

6. Mature gemmae of (19) 20–22 cells; dorsal leaf cells weakly, and only locally, conically tuberculate....*C. diaphana* (typical)

6. Mature gemmae of 16 cells; dorsal and keelar cells strongly tuberculate. *C. diaphana cristulata*

3. Lobes rounded or broadly obtuse at apex; lobules (on any one plant) usually rather uniform in size and development; lobes with cells smooth (exc. *C. macounii*, in which lobes are broadly rounded at apex); gemmae (where known) smooth-margined, without organs of attachment; lobules with apical teeth 2 (3–4)-celled....7.

7. Dorsal lobes broadly oblong-ovate, broadly rounded at apex, uniformly and prominently tuberculate; lobules uniformly developed and inflated. *C. macounii*

7. Dorsal lobes ovate, obtuse to narrowly rounded at the narrowed apex, smooth (the cells convex but not armed)....8.

8. Lobes narrowly ovate, bearing small lobules (their maximal length, to apical tooth, 0.35 × that of lobe)....9.

9. Lobules of some leaves inflated (rarely all or almost all vestigial, then

with 2-celled apical teeth); cells commonly with small but distinct trigones; oil-bodies coarse-segmented.....*C. subcristata*

9. lobules uniformly vestigial, bearing apical teeth (2) 3–4 cells long; cells quite leptodermous; oil-bodies fine-segmented.....*C. setiloba*

8. Lobes broadly ovate to elliptical-ovate, bearing large lobules (when inflated 0.65–0.9 × length of lobes, but often reduced to a narrow fold 0.6–0.8 × the length of lobes).....10.

10. Leaves usually complanate, the lobule normal, inflated, with the apical, 2-celled tooth distinct; normally lobulate leaves with lobule typically 0.8–0.9 × the length of lobe, the area of the lobule virtually equal to that of lobe; ♀ bracts more or less keeled, the lobule well-developed; gemmae of up to 34 cells; lobes subrotund; cells with 3–6 small oil-bodies. *C. minutissima* subsp. *minutissima*

10. Leaves usually explanate, the lobule merely a fold, lying virtually in the same plane as the erect or quarrose lobe, devoid of a distinct apical tooth; the occasional, normally lobulate leaves with lobule merely 0.6–0.8 × the length of lobe, the area less than 0.6–0.8 × that of lobe; lobes ovate, more or less elongated; ♀ bracts with lobules obsolete, represented by a mere narrow fold not separated by a discrete (at best low and rounded) keel from the lobe; gemmae of 14–16 cells; cells typically with 1–2 large oil-bodies.....*C. minutissima* subsp. *myriocarpa*

SECTIO MINUTISSIMAE sectio nova

Propagulae rotundatae in marginibus, sine cellulis tumidis rhizoido-initialibus; folia apice rotundata vel obtusa, cellulis non quasi tuberculos productis.

Plants not heterophyllous, the leaves with lobes narrowly to broadly rounded at apex, ovate to broadly ovate, less than 1.5 times as long as wide. Lobules variable, but not strongly variable on individual plants, always with a well-marked apical tooth 2 cells long or more, lying in the plane of the lobule; stylus absent. Cells convex, but never conoidally produced, the leaves and perianths consequently essentially smooth; trigones minute or absent, the cells delicate; oil-bodies distinctly segmented (finely so in *C. setiloba*); ocelli lacking. Gemmae variable in position, often without sharply delimited mode of occurrence, on antical and/or postical faces of lobes, and sometimes some from marginal cells, 16–36-celled, broad-ellipsoidal, faintly crenulate marginally but never angulate; lacking rhizoid-initials (slime cells).

Female bracts with rounded or obtuse lobes, and usually similar lobules. Perianth not distinctly flattened, sharply 5-carinate in distal half, the keels unmodified, unarmed; beak distinct.

Sectio Minutissimae includes four regional taxa, *C. subcristata*, *C. setiloba*, *C. minutissima*, and *C. myriocarpa*. As is developed subsequently, the last appears to be merely a race of *C. minutissima*. The group is characterized by the primitive features: rounded leaf-lobes; unmodified gemmae; simple perianths; totally unspecialized cells; rather coarse-segmented oil-bodies; unspecialized lobules. Only *C. setiloba*, with its obsolete lobules and fine-segmented (papillose appearing) oil-bodies deviates to any degree.

Cololejeunea minutissima (Smith) Schiffn.

Among the most polymorphic and poorly understood sections of *Cololejeunea* is the complex here referred to as the *C. minutissima-myriocarpa* complex. The writer believes that *C. minutissima* consists of a series of geographically more or

less isolated segregates, which cannot be separated from each other as distinct species. The difficulty inherent in their recognition is further enhanced by a great "somatic" plasticity, or responsiveness to varied environmental conditions. As a consequence, with study of long series of specimens, the distinctions customarily relied upon for "species" in this complex totally disappear. In this area, the *C. minutissima-myriocarpa* complex is represented by only two taxa, which appear to intergrade almost imperceptibly. The South African *C. myriantha* Herzog represents a scarcely distinct segment of this same complex,[3] while *C. dissita* E. W. Jones, also from Africa, appears to be a closely allied species (or subspecies) of this complex. Horikawa (1934) reports *C. minutissima* (as *Aphanolejeunea minutissima*) from India, and the Bonin and Liukiu Islands of Japan,[4] and also describes as new *Physocolea magnilobula* Horikawa, from Formosa, a species bearing at least superficial resemblances to *C. minutissima*. From a consideration of these facts, it appears clear that this complex is of world-wide distribution in the tropical and subtropical regions of the globe, excepting perhaps the Australian and adjacent Malayan and Pacific regions, with extensions northward in Oceanic areas to southern Japan, southeastern United States, and to oceanic, western Europe. The two segments of the complex regionally represented are as follows:

Cololejeunea minutissima subsp. *minutissima* (Smith) Schiffn.

Jungermannia minutissima Smith, *in* Sowerby, Eng. Bot., *pl. 1633*, 1806.
Jungermannia inconspicua Raddi, Mem. Mat. e Fis. Soc. Ital. Sci. Mod. **18:** 34, *pl. 5, f. 2*, 1820.
Lejeunea minutissima Dumort., Comm. Bot. 111, 1822; G. L. et N., Syn. Hep. 387, 1845.
Jungermannia parvula Wils. et Hook, *in* Drummond, Musc. Amer. St. Merid. 172, 1841.
Lejeunea taylori Spruce, Ann. Nat. Hist. Ser. II, **4:** 116, 1849.
Lejeunea inconspicua De Not., Mem. Acc. Tor., Ser. 2, **22:** 386, *pl. 5, f. 27*, 165.
Lejeunea parvula Aust., *in* Lindberg, Acta Soc. Sci. Fenn. **10:** 481, 1875.
Lejeunea (*Colo-Lejeunea*) *minutissima* Spruce, Hep. Amaz. et And. 293, 1884.
Lejeunea (*Colo-Lejeunea*) *parvula* Stephani, Bot. Gaz. **17:** 171, 1892.
Cololejeunea minutissima Schiffn., *in* Engler-Prantl, Nat. Pfl.-Fam. **1**(3): 122, 1895; Evans,

[3] The report of *C. minutissima* by Sim (Trans. Royal Soc. S. Afr. **15:** 49, 1926) from South Africa is evidently based on the plants which Herzog considers to represent a separate species, *C. myriantha*. At first glance the cytological differences cited for this latter by Arnell (1953, p. 165) appear impressive, but, as pointed out by Schuster and Hattori (1954), the description of the oil-bodies given by Arnell is based on disintegrating oil-bodies and not normal ones. On the basis of Arnell's (1953) and Herzog's (1951) figures and descriptions I cannot conclude that the cited differences supposedly distinguishing *C. myriantha* are more than racial; therefore I propose the combination: *Cololejeunea minutissima* subsp. *myriantha* (Herzog) comb. n. (= *Physocolea myriantha* Herzog, Mem. Soc. F. Fl. Fennica **27:** 102, 1951).

[4] *Cololejeunea orbiculata* (Herzog) Hattori, from China and Japan, may be the same taxon as *C. minutissima* of Horikawa. Although Hattori maintains the former as a distinct species, it is admitted (Schuster and Hattori, 1954, p. 62) that it is very closely allied to *C. minutissima*. The plant possesses in general 3–7 oil-bodies per cell, much as in *C. minutissima minutissima*. Hattori (1952, p. 37) ascribes both *C. orbiculata* and *C. minutissima* to the flora of Japan, thus indicating that two sympatric taxa of this complex occur in Japan.

Mem. Torrey Bot. Club **8**: 166; Evans, Bull. Torrey Bot. Club **38**: 282, *fig. 2A* (gemma), 1911; Müller, *in* Rabenhorst's Kryptogamenfl. **6**(2): 673, *fig. 188*, 1916.

Cololejeunea inconspicua Massal., Atti Istit. Veneto **71**: 1275, 1912.

Physocolea minutissima Steph., Sp. Hep. **5**: 914, 1916.

Aphanolejeunea minutissima Horikawa, Jour. Sci. Hiroshima Univ. Ser. B, Div. 2, **2**(2): 283, 1934.

Plants pure to yellowish green, usually creeping and as isolated, scattered plants, rarely in loosely caespitose-depressed patches; shoots 275–450 μ wide (lobulate, xeromorphic phases) to 450–600 μ wide (explanate-leaved, lax phases). Stems closely adnate to substrate, 34–50 μ thick, somewhat geniculate at nodes, irregularly, usually freely, divaricately branching, the shoots 5–13 mm long; cortical cells 15–17 x 25–30 μ. Leaves distant to contiguous, *varying greatly with differences in shade and humidity*. Xeromorphic leaves lobulate, with dorsal lobe strongly convex, never squarrose, spreading to strongly spreading, broadly ovate to subrotund, mostly (150) 200–250 μ long x (140) 170–200 μ wide (its length usually 1.1–1.4 × that of the lobule); margins of lobe regularly and strongly crenulate because of the rounded and projecting cells; dorsal base arching virtually or quite across stem; apex very broadly rounded to broadly obtuse; keel strongly arched, 135–240 μ long, forming a continuous arched line with the free postical margin of lobe; *lobule very large, strongly inflated*, ovate, (125) 150–225 μ long x 100–175 μ wide, its cells convex but never tuberculate, its *apex marked by a prominent tooth 2 cells long* (at whose base occurs the hyaline papilla, typically entally displaced); proximal lobular tooth obtuse or subacute; stylus reduced to an ephemeral slime papilla. Leaves of shade forms *usually explanate*, squarrose and standing stiffly erect (with antical margins at right angles to dorsal surface of stems), the *lobules reduced to a narrow, ill-defined fold* along the postical margin, lying in virtually the same plane as the lobe (the keel absent or vestigial); shade leaves often larger (260–300 μ long x 190–200 μ wide) and with lobes more narrowly ovate, sometimes less rounded distally. Cells strongly convex everywhere, but never elevated as conical tubercles, exceedingly thin-walled, on margins (13) 15–18 μ, medially *ca.* 18–20 (22) μ, polygonal, devoid of trigones and intermediate thickenings; oil-bodies mostly (2) 3–5 or 4–6 per cell, ovoid to ellipsoidal or fusiform, rarely rotund, segmented, varying from 3–5 x 7 μ to 2–2.5 x 7–9 μ; gemmiparous leaves often with more frequent (9–12), smaller, rotund oil-bodies. Asexual reproduction by discoid gemmae, arising indiscriminately from either the *antical surface or the margins* of the lobe; gemmae large, plate-like, 60 x 68 to 80–90 x 100–110 μ, usually *formed of 26–34, occasionally 38, cells at maturity*, originating both from leaves and ♀ bracts, sometimes giving rise to secondary gemmae from their margins; central portions of gemmae at maturity rarely 2 cell-layers thick.

Autoecious. Female inflorescence usually on an elongate branch (rarely on a short branch), producing a single (rarely 2) subfloral innovation; *bracts somewhat complanate, distinctly unequally to subequally 2-lobed* (the sinus sometimes quite shallow, at other times *extending 0.2–0.35 × the lobe-length*); *lobes narrowly oblong*, rounded to obtuse distally, 320–420 μ long x 120–170 (250) μ wide; *lobule similar, slightly shorter* (260–350 μ long x (70) 100–125 μ wide;) margins of bracts crenulate like leaves; keel more or less discrete. Perianth obovoid, more or less exserted at maturity (the base becoming somewhat stipitate), 500 μ long x 300–350 μ wide, cuneate basally, sharply 5-carinate on distal half, the surface weakly papillose owing to the convex cells. Androecia spicate, on short lateral branches (which do not usually proliferate distally) or on elongate branches (then usually becoming intercalary), the bracts in 2–8 pairs, imbricated, strongly saccate, somewhat unequally bilobed, the lobes rounded to very obtuse; antheridia singly or in pairs; spores greenish, with a delicately verruculose wall, 17 μ in shorter diameter.

TYPE LOCALITY: England.

DISTRIBUTION.—Occurring widespread in both the New World and the Old World, in regions contiguous to the Atlantic Ocean, distributed from western Europe (in oceanic and suboceanic regions, northward to coastal France, Eng-

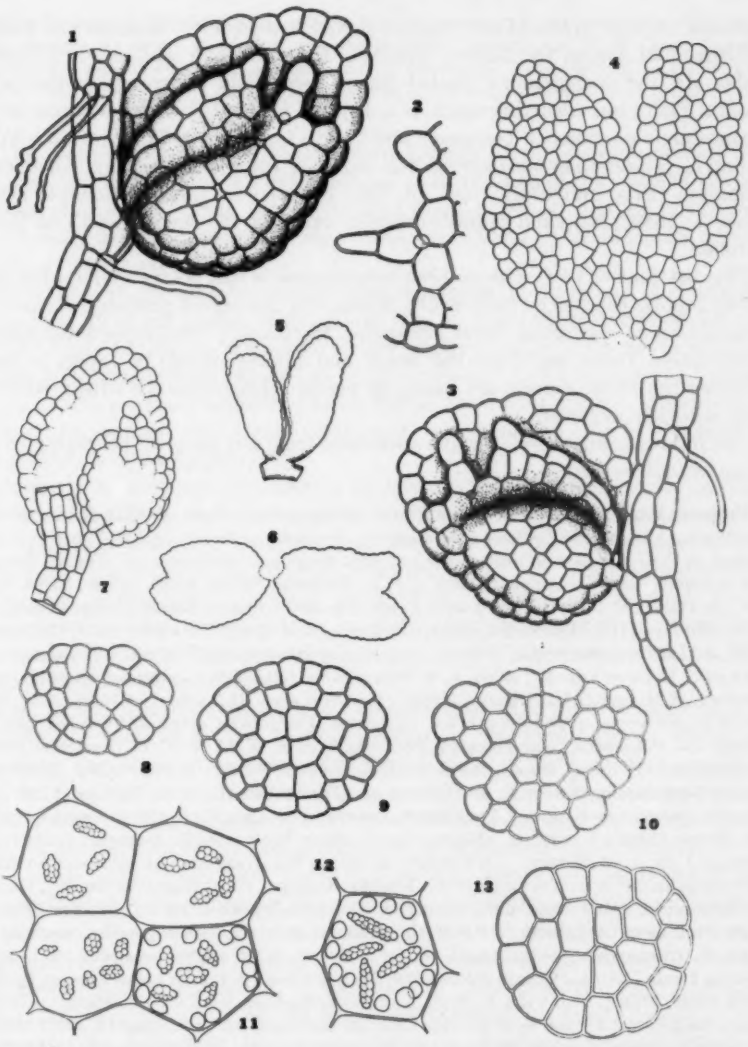


FIG. VI. *Cololejeunea minutissima minutissima* (Sm.) Schiffn. 1, 3. Shoot-sectors with leaves, postical view, in Fig. 3 somewhat flattened, the hyaline papillae indicated, the preapical tooth unusually well-developed (× 260); 2. Apex of flattened lobule, ental view (× 460); 4. Female bract (× 130); 5. Two bracts, in situ (× 65); 6. Two bracts, flattened (× 65); 7. Somewhat abnormal and juvenile leaf, with atypically formed apical tooth (× 130); 8–10 gemmae, showing variation in size on a single plant, but all of the *"minutissima"* type (× 275); 11. Median cells (× 860); 12. Median cell (× 1050); 13. Unusually small gemma (× 460). (Figs. 1–3, 11–12, Gulf Coast Research Laboratory, Miss., *Schuster*; 4–7, North Carolina, *Schuster 28377*; 8–10, Georgia, *Schuster 31480*; 13, Handsboro, Miss., *Schuster 20381*).

land and Ireland, in the Mediterranean region eastward to Dalmatia and Italy), southward to Africa, the Azores, Madeira, Bermuda and southeastern United States. In the southeastern United States essentially restricted to the outer Coastal Plain, but occurring again as a disjunct element at low elevations in the mountainous portions of Tennessee and North Carolina; grading into the West Indian *C. minutissima myriocarpa*. The report of the species from the District of Columbia (Frye and Clark, 1947, p. 884) is based on the questionable list of Lehnert (1886). No valid published report exists of the species north of North Carolina.

The distribution of *C. minutissima minutissima* is still poorly understood. Sim (1926) reports the species from South Africa, but this report probably is based on *C. minutissima myriantha* (Herz.) Schuster. Horikawa (1934) reports the species from eastern India, and from the Bonin and Liukiu Islands of Japan (s. lat.). Whether the latter reports are based on plants referable to the subsp. *minutissima* is totally uncertain.

The following are representative specimens from our area, all belonging to the subsp. *minutissima:*

Virginia: PRINCESS ANNE CO. (Cape Henry, Seashore State Park, *RMS & P.M. Patterson 34553*, p.p., mixed with *Leptocolea cardiocarpa, Frullania obcordata* and *F. kunzei*; all four species at their northern limital points in North America!); NORFOLK CO. (Dismal Swamp, at n.e. side of Lake Drummond, *RMS & P.M. Patterson 34530c, 34550, 34552c, 34563, 34556* p.p.; in *34556* and *34563* admixed with *Leptocolea cardiocarpa*).[5] **North Carolina:** DARE CO. (w. of Kill Devil Hill Monument, near Kitty Hawk, *R.M. & O.M. Schuster 28377*; Collington, *R.M. & O.M. Schuster 28331*; 5–8 mi. s. of Manns Harbor, *RMS 28380c*); PENDER CO. (n. bank of N.E. Cape Fear R., 10 mi. n. of Wilmington, *RMS 31811*); DURHAM CO. (4 mi. w. of Durham, *R.M. and O.M. Schuster 32301c*); COLUMBUS CO. (1.5 mi. e. of Whiteville, *RMS and H.L. Blomquist 29490*); WAKE CO. (Hemlock Bluff near Carey, *RMS 28590, 28717c*); STOKES CO. (Cascades, near Hanging Rock State Park, *RMS & H. L. Blomquist 28250*); WASHINGTON CO. (near Roper, *RMS & O.M. Schuster 28369a, 28369b, 28364, 28356* p.p., among *Leptocolea cardiocarpa*); BRUNSWICK CO. (Holden Beach, *H. L. Blomquist 7349* p.p., among *Leptocolea cardiocarpa*). **Tennessee:** ANDERSON CO. (*fide* Sharp, 1939). **South Carolina:** *fide* Evans (1902); HORRY CO. (Myrtle Beach State Park, *RMS*). **Georgia:** LIBERTY CO. (Swamp 1 mi. n. of Midway, *RMS 31415b, 31480*; in No. *31480* with an approach to subsp. *myriocarpa* in the ♀ bracts and leaves). **Florida:** ALACHUA CO. ("Buzzards Roost", 7 mi. w. of Gainesville, *RMS 33350* p.p., among *C. contractiloba*). COLLIER CO. (Collier-Seminole State Park near Everglades, *RMS 26150, 26158c*; closely approaching subsp. *myriocarpa*); LAKE CO. (Alexander Springs, Ocala National Forest, *RMS 33436a*). MARION CO. (Juniper Springs, Ocala National Forest, *RMS 31939*; Juniper Creek, 3–4 miles below Juniper Springs, *RMS 33399, 33450b*; Oklawaha R., 4 mi. e. of Silver Springs, *RMS 22507a, 22457a*). DADE CO. (Hammock Forest 5–6 mi. w. of Florida City, on Loveland Rd., *RMS 22561h, 22677, 22758a*; all intergrading into subsp. *myriocarpa*). HILLSBOROUGH CO. (Hillsborough R. State Park, *RMS 33913, 33910b, 33923a, 33934a, 22858, 22873b*; in part grading into subsp. *myriocarpa*, in *RMS 22873b* with the gemmae dorsal, only 12–24, rarely 24–26-celled). Also reported from Broward, Glades, Lee, Polk, Seminole and St. Lucie Cos. (Redfearn, 1952), without any attempt at discrimination between the typical subspecies, and subsp. *myriocarpa*. **Alabama:** fide Evans (1938); BALDWIN CO. (Gulf Shores State Park, *RMS*). **Mississippi:** Harrison Co. (near Handsboro, w. of Biloxi, *RMS 20397, 20392a, 20396, 20400a, 20581*; *No.*

[5] In the preceding section of this series, *L. cardiocarpa* was not reported north of North Carolina. With these recent reports the genus and species are established at a new northern limital point in this hemisphere.

20381 with gemmae 15–16–20-celled, with explanate leaves, very close to subsp. *myriocarpa*; near Saucier, ca 20 mi. n. of Gulfport, *RMS 19750*). Jackson Co. (Gulf Coast Research Laboratory near Ocean Springs, *RMS, plate*). **Louisiana:** Avoca Island, and Bateman's Island (fide Svihla, 1939). **Texas:** CAMERON CO. (Rio Hondo, *Runyon*, fide Frye and Clark, 1947).

The plants from extreme southeastern Georgia, from extreme coastal Mississippi, and from southern Florida almost all show some of the traits of the subspecies *myriocarpa*. Some specimens here cited under subspecies *minutissima* could easily be considered nearer *myriocarpa*, depending on the arbitrary point at which a distinction is made.

ECOLOGY.—*C. minutissima minutissima* is perhaps the most light- and drought-tolerant of all of our species of the genus. It is able to undergo ecesis on the bark of such trees as *Quercus virginiana* in dry, exposed areas (such as the sand-hill region of central Florida) as well as on *Q. virginiana* in the areas behind coastal dunes, where a certain amount of salt spray occurs during storms. The species is, in our area, almost exclusively corticolous (although the closely allied subsp. *myriocarpa* is often epiphyllous).

Towards the northern periphery of its range (in Virginia and North Carolina) commonly on the bark of *Acer saccharinum*, *A. rubrum*, *Nyssa sylvatica biflora*, *Ilex opaca*, *Quercus* spp., occasionally on that of *Asimina triloba*, *Salix nigra*, or *Betula nigra*, most often in swamps. Here associated are *Frullania inflata*, *brittoniae* and *eboracensis*, *Leptocolea cardiocarpa*, *Rectolejeunea maxonii*, *Cololejeunea biddlecomiae*, *Leucolejeunea unciloba*, *Radula complanata*, occasionally *Frullania squarrosa*, *F. asagrayana*, *F. kunzei* and *F. obcordata*, as well as *Metzgeria furcata* and *Lejeunea flava*.

Further southward on the bark of *Taxodium distichum*, *Sabal palmetto*, *Myrica cerifera*, *Magnolia virginiana*, *Quercus virginiana*, *Erythrina herbacea*, *Elaphrium simaruba*, and other trees. Associated here are most of the preceding species, as well as *Frullania donellii*, *Leucolejeunea conchifolia*, *Cololejeunea diaphana* and *contractiloba*, *Radula calosiensis*, more rarely *Mastigolejeunea auriculata*, *Cheilolejeunea clausa*, *Brachiolejeunea bahamensis* and *Ptychocoleus heterophyllus*. On the fibrous, anomalous "bark" of *Sabal palmetto* also with *Clasmatocolea doellingeri*, *Cephaloziella rhizantha*, the alga *Trentepohlia*, and the lichen *Chiodecton sanguineum*. In southern Florida occasionally able to undergo ecesis on small twigs (as of *Xanthoxylum fagara*; then with *Frullania riojaneirensis*, *F. donellii*, *Diplasiolejeunea rudolphiana*, *Caudalejeunea lehmanniana*, and *Lejeunea bullata*). Also occasionally on the twigs and branches of *Azalea serrulata* (with *Lejeunea flava*, *L. bullata*, *Leptocolea cardiocarpa*, *Frullania donellii*, *Diplasiolejeunea rudolphiana*). In both of the latter cases, occurring in humid, dense hammock forest. Contrastingly, also able to undergo ecesis on the branches of scrubby *Quercus virginiana*, ("*Q. gemminata*") in open Oak Scrub, associated with *Leptocolea*, *Leucolejeunea conchifolia* and *Frullania donellii*.

The most marked characteristic of the species is the consistent occurrence as a pioneer, most often associated with *Leptocolea cardiocarpa*, *Frullania kunzei*, *donellii*, *obcordata* or *riojaneirensis* and *Leucolejeunea conchifolia* or *unciloba*, as well as (southward) *Diplasiolejeunea* and *Lejeunea bullata*. The plant is very

tolerant of wide differences in moisture conditions, but appears quite intolerant of any competition with coarser species. The association with *Leptocolea* is a particularly frequent one.

VARIATION.—*C. minutissima*, judging from the European literature, is a relatively slightly variable species. However, in the southeastern states this species varies to an extreme degree, correlated with differences in saturation-deficit. The forms occurring in relatively insolated sites (as on the bark of Live Oak, in partial sun), bear the subrotund, strongly convex, lobulate leaves as they are described and figured by Macvicar (1926), Müller (1916) and Cesares-Gil (1919) for the European plants. Such plants are smaller and more rigid than many of our lax plants; they show very large, strongly inflated lobules that average fully 0.8 times the size of the dorsal lobes. Plants of this type are usually also distinctly yellowish-tinged.

However, almost as frequent as the "typical" form of the species is the plant of more mesic, more humid sites, in which the leaves are quite explanate, tend to become somewhat obtusely pointed distally, are squarrose, and have the lobule reduced to an ill-defined fold, lying in virtually the same plane as the squarrose or erect lobe. Such plants are larger (up to 600 μ wide), laxer, less rigid, and softer-textured; they are almost a pure green, with little of the yellow tinge so frequently characteristic of the xeromorphic plant. The lax extremes sometimes totally fail to show lobulate leaves, and they may cause the beginner difficulty, even in the assignation to the correct family. Such plants appear to intergrade completely with *C. minutissima myriocarpa*.

The "typical" forms of the species are characterized by distinctly complicate ♀ bracts, which are nearly subequally bilobed, with a discrete sinus 0.2–0.35 times the length of the bract; such bracts have well-developed lobules that are oblong like the lobes, and are virtually as broad and as long as the lobes. Such a bract is figured by Müller (1916) and is represented in Fig. VI: 4 (based on *RMS 28377*, North Carolina). Such bracts are usually smaller, with narrowly oblong lobes (320–340 μ long x 120–150 μ wide). By contrast, the lax extreme of the species shows bracts that very closely approach those of *C. myriocarpa* in being very shallowly, very unequally bilobed, with the sinus often a mere vestigial notch. Such bracts are often larger (lobe 420 μ long x 250 μ broad) but bear strongly reduced lobules (only a narrow fold 70 μ broad x 350 μ long). Such bracts are shown on Fig. VII: 7, 8 (from material collected in Georgia, *RMS 31480*; these plants, even though approaching *C. myriocarpa*, have the very large gemmae varying from 30 to 38 cells in size).

DIFFERENTIATION.—The xeromorphic phase of the species, with inflated, well-developed lobules, can scarcely be confused with any of our other species of *Cololejeunea*. It differs from these in the rounded apices of the broadly ovate or suborbicular lobes, in the extremely large size of the lobule (which may be over 0.8 times the area of the lobe), and in the peculiar, many-celled gemmae. The total lack of any tendency towards development of cellular, conical protuberances of the leaf-cells serves to separate the species from all but *C. subcristata* and *setiloba*. The latter species differ at once from all phases of *C. minutissima* in (1)

the form of the gemmae; (2) the ovate-pointed, narrow leaves; (3) the very small size of the lobules, never over 0.35 times the length of the lobe.

Confusion of the xeromorphic, lobulate extreme of the species is more likely to occur with such unrelated species as *Lejeunea* (*Microlejeunea*) *ulicina* (or *bullata*). The very large size of the lobule, the non-tuberculate leaves, the rounded apex of the broadly ovate lobe all give the species an appearance suggestive of *Microlejeunea*. Indeed, both Hooker and Ekart, in the classical days of bryology, confused these two species. However, the total lack of underleaves, and the peculiar 2-celled apical tooth of the lobules, serve at once to separate *C. minutissima* from *Microlejeunea*.

The identification of the explanate-leaved phases of the species is a matter of great difficulty at times. As is emphasized under *C. minutissima myriocarpa*, the elobulate extremes of *C. minutissima minutissima* are almost impossible to separate from subsp. *myriocarpa*. However, *C. minutissima minutissima* supposedly has gemmae that attain a larger size (90 x 110 μ, occasionally 100 x 125 μ), are formed of usually 28–34, occasionally 38 cells at maturity, and the cells typically possess (on non-gemmiparous leaves) 3–5 oil-bodies per cell. By contrast, "*C. myriocarpa*" is stated (Evans, 1911) to have smaller gemmae, 14–16 cells in extent, and has (in the Florida material referred to it by the writer) 1–2, rarely 3 very large oil-bodies per cell. Unfortunately, even these differences do not prove constant. For example, study of explanate-leaved phases of this difficult complex has shown a distressing variation in the mature gemma size. This ranges from the "*C. minutissima* extreme" almost to the "*C. myriocarpa* extreme." This range is clearly shown by three collections, all of which, on the basis of purely vegetative characters could well be referred to *C. minutissima* subsp. *myriocarpa*; these collections are summarized in the following table:

Specimen:	*RMS 31480*, Georgia: Clay Co.	*RMS 22873*, Fla.: Hillsborough Co.	RMS *20381*, Miss.: Harrison Co.
Gemmae	90 × 110–100 × 125 μ, of 34–38 cells at dehiscence	60 × 68–82 × 104 μ, of 23–26 cells at dehiscence	45 × 50–55 × 65 μ, of 16–20 cells at dehiscence

Where a line is to be drawn here between "*C. minutissima*" and "*C. myriocarpa*" is quite unclear, if at all possible. Suggestive, in this connection, are the plants from Cuba, determined by Evans as *C. myriocarpa*, which have gemmae of 20–24 cells. These plants almost totally match such plants as those of *RMS 22873*. It also seems strange that the very widespread *C. minutissima* should be restricted, in the New World, to the region north of the West Indies, while *C. myriocarpa* should be restricted to the region south of the United States. Evans (1911), while admitting that *C. myriocarpa* is very close to *C. minutissima*, retains the traditional distinction between them, restricts the former to the area south of the United States, the latter to the southeastern United States and Bermuda. Critical work seems to demonstrate that a single species is involved. This conclusion was implicit in the treatment of the complex by Schuster (Schuster and Hattori, 1954).

Cololejeunea minutissima subsp. *myriocarpa* (Nees et Mont.) comb. n.

Lejeunea myriocarpa Nees et Mont., *in* Ramon de la Sagra, Hist. Fis. Pol. y Natur. Cuba **9**: 473, 1845.

Lejeunea epiphyta Gottsche, *in* G. L. and N., Syn. Hep., 391, 1845.

Lejeunea wrightii Gottsche, *in* Wright, Hep. Cubensis (Exsiccatae, *sine descr.*); Stephani, Bot. Gaz. **17**: 172, 1892 (*nomen nudum*).

Lejeunea (*Colo-Lejeunea*) *myriocarpa* Stephani, Hedwigia **29**: 89, 1890.

Lejeunea (*Cololejeunea*) *heteromorpha* Spruce, Jour. Linn. Soc. Bot. **30**: 348, *pl. 24, f. 5–9*, 1894.

Cololejeunea myriocarpa Evans, Bull. Torrey Bot. Club **38**: 256, 1911.

Plants bright to yellowish-green, creeping, growing in thin mats or as isolated plants; shoots 400–650 μ wide; stems adnate to substrate, irregularly branched, the branches usually at nearly 90° to stem, similar to stem; stems 40–50 μ in diam., slender, slightly zigzag; cortical cells *ca.* 15–18 x 24–30 μ. Leaves usually distant, rarely contiguous, the lobe very obliquely to (usually) widely spreading, *narrowly to broadly ovate, often standing stiffly erect or squarrose* (frequently to the degree that the postical surface of the lobe becomes visible in antical aspect); lobe obtuse to narrowly rounded at apex, variable in size (mostly 300–350 μ long x 190–200 μ wide), the margin crenulate with projecting rounded cells that are never conically produced. Lobule polymorphic: *usually represented by a mere ill-defined, narrow, indistinct fold*, (up to 80 x 220 μ in size) connected to the lobe by an ill-defined and obscure, rounded keel, with an indistinct apical tooth and reduced, shallow sinus; hyaline papilla marginal but slightly entally displaced; lobules very rarely ± inflated (then much as in *C. minutissima*, but *their area at most 0.6–0.65* × *that of the lobe*), their apices then marked with a 2-celled apical tooth. Cells thin-walled, virtually devoid of trigones, without intermediate thickenings, *ca.* (14) 16–18 μ on margins, 16–19 x 18–22 μ near leaf-middle, 22 μ near base; cells of middle of lobule *ca.* 10–14 x 12–15 μ; *oil-bodies large*, mostly 3.5 x 6 to 4 x 12 μ or 4.5 x 10 μ, broadly to narrowly ellipsoidal or fusiform in shape, *finely segmented* (appearing coarsely papillose), usually *1–2 large ones per cell*, more rarely 2–3 somewhat smaller ones. Asexual reproduction by discoid gemmae, these subcircular, formed of *14–16* or up to 20–29 *cells*, formed from two segments, evenly crenulate on margins, not developing slime-cells.

Autoecious. Female inflorescence on an elongated or very short branch, if on an elongated branch innovating on one side (more rarely on both); bracts similar to leaves, but slightly larger (varying from 265 x 230 μ wide to 395 x 290–325 μ wide, up to 450 x 300 μ, including the vestigial lobule), erect-spreading, narrowly to broadly ovate, the *lobule reduced to a narrow fold* (*ca.* 300 x 45–60 μ), *ill-defined and rounded or obtuse at apex*, separated from lobe by a slight to *vestigial sinus*; keel between lobe and lobule *virtually absent*; bract margins crenulate like leaf-margins. Perianth obovoid, 450–460 μ long x 280–300 μ wide, sharply 5-carinate for *ca.* 0.5 × its length, the keels somewhat roughened from projecting cells; beak short and broad, sometimes almost obsolete; perianth often conspicuously stipitate and becoming long-exserted with age. Male inflorescences usually on short lateral branches, very variable in length and number of bracts, usually with 2–4 pairs of bracts, the latter mostly approximate to subimbricate, erect-spreading or erect, mostly subequally and shallowly bilobed, the keel strongly arched, the lobule somewhat shorter than the lobe; mon- or diandrous. Capsule *ca.* 200 μ in diam.; spores greenish, delicately verruculose, *ca.* 14 μ in shorter diam.; elaters *ca.* 3 μ in diam.

TYPE: Havana, Cuba (Ramon de la Sagra).

DISTRIBUTION.—Appearing restricted largely to the West Indies (Cuba, St. John and St. Vincent in the Virgin Islands, Jamaica, Puerto Rico), but also occurring on the North American continent in Mexico (Karsten) and extending into southern Florida. Evans (1911) has summarized the distribution of this taxon, under the name *C. myriocarpa*.

Florida: DADE CO. (Section 24 of Long Key pineland, Everglade Keys, Everglades Natl. Park, *RMS 22029b*, plate; Paradise Key, Everglades Ntl. Park, *RMS 22586*, plate; Timms

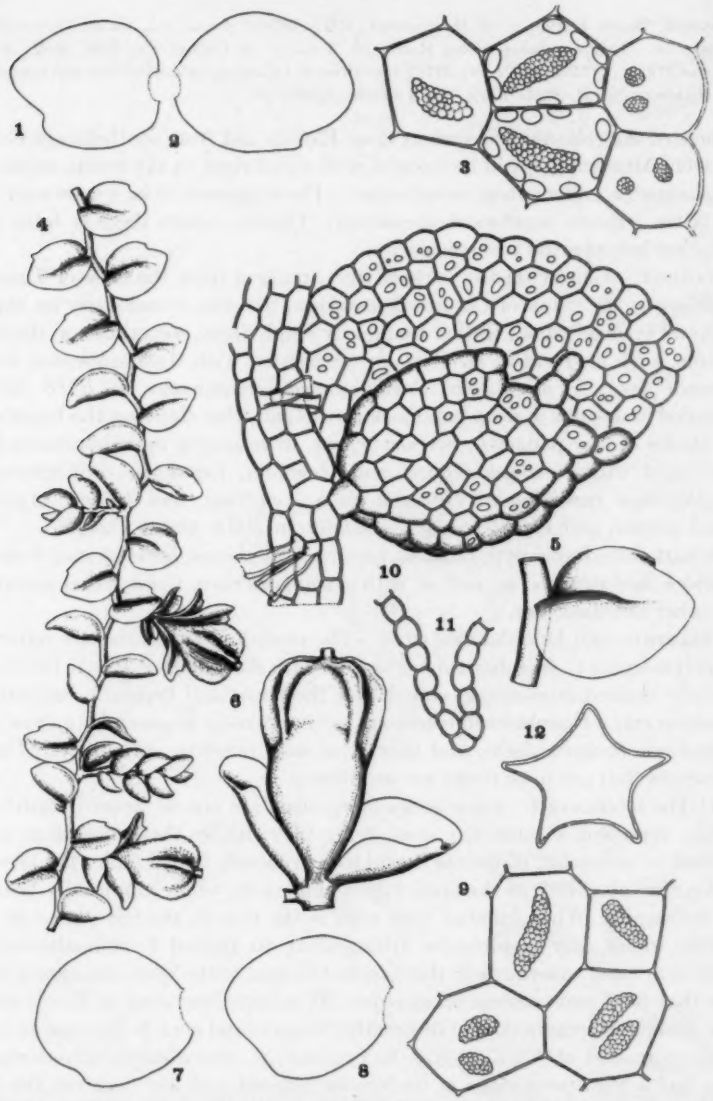


FIG. VII. *Cololejeunea minutissima myriocarpa* (Nees and Mont.) Schust. 1–2. Female bracts of a single inflorescence (× 82); 3. Leaf cells, the margin at the right, chloroplasts drawn in in 2 cells (× 810); 4. Antical view of explanate-leaved shoot with 2 androecia and 2 perianths (× 35); 5. Explanate leaf, in situ, antical view, showing squarrose lobe (× 80); 6. Perianth and bracts, postical view (× 76); 7–8. Two bracts (× 64); 9. Median cells (× 830); 10. Shoot-sector, postical view, with 2 rhizoid fascicles and a leaf of the lobulate type; oil-bodies drawn in (× 320); 11. Cross-section of perianth-keel (× 210); 12. Cross-section of perianth (× 70). (Figs. 1–2, 4–6, 11–12, Paradise Key, Fla., *Schuster 22586*; 3, 10, Fla., *Schuster 22029b*; Figs. 7–8, Georgia, *Schuster 31480*).

Hammock, Bauer Drive, n. of Homestead, *RMS 33701e*, trans. ad. subsp. *minutissima*). MONROE CO. (In Everglades along Route 94, 3 mi. s. of Collier Co. line, *R.M. & O.M. Schuster 31741a, 31759a, 31761*; No *31761* transitional to subsp. *minutissima*). HILLSBOROUGH CO. (Hillsborough R. State Park, *RMS 33909b, 33908c*).

Some of the collections elsewhere from Florida and from southeastern Georgia and from Mississippi could be referred with equal right to the subsp. *myriocarpa* (see discussion under subsp. *minutissima*). There appears to be a wide area, from the latter regions, southward to southern Florida, where there is total intergradation between the two subspecies.

ECOLOGY.—Chiefly on the bark of trees, ranging from the base of *Taxodium ascendens* to the trunk of *Chrysobalanus icaco*, but also occasionally on exposed roots and on dead wood. Rather frequently epiphyllous, sometimes on the leaves of ferns, such as *Tectaria heracleifolia* (associated with *Aphanolejeunea evansii*, *Lejeunea flava*, *L. minutiloba*, *Caudalejeunea lehmanniana*, in *RMS 33701e*), in shaded lime-sinks in deep hammock forests; at other times on the bases of the leaf-blades of saw palmetto, *Serenoa repens*, in relatively open hammock forest (associated with *Frullania kunzei* and *obcordata*, *Leptocolea cardiocarpa*, *Diplasiolejeunea rudolphiana*, *Lejeunea flava*, *longifissa*, and *bullata*, *Aphanolejeunea evansii*, and *Leucolejeunea conchifolia*, in *RMS 33908c*, *33909b*).

On bark often found with *Diplasiolejeunea rudolphiana*, *Rectolejeunea brittoniae*, *Cheilolejeunea rigidula*, as well as with *Aphanolejeunea*, *Cololejeunea subcristata*, and other Lejeuneaceae.

VARIATION AND DIFFERENTIATION.—The preceding collections are referred to the polymorphic *C. minutissima myriocarpa* with some doubts. Evans (1911), who carefully studied *myriocarpa*, stated that the latter and typical *C. minutissima* "share so many characters in common that it is almost impossible to draw sharp distinctions between them, and they rival each other in variability." The few differences that are to be found are as follows:

(1) The lobules of *C. minutissima myriocarpa* are almost never inflated; they usually represent a mere flat area, lying in virtually the same plane as the suberect or somewhat squarrose dorsal lobe or loosely folded under the lobe; and are marked obscurely at the apex with a single cell, whose tip usually bears the hyaline papilla. When inflated (and such is the case in the few plants of *RMS 22029b*, which may possibly be intermediate to typical *C. minutissima*), the lobule is at most two-thirds or three-fifths the area of the lobe, and agrees closely with that of *C. minutissima minutissima*. It is more common, as Evans emphasizes, to find all plants devoid of inflated lobules (and such is the case in all the plants examined of *RMS 22586*). In contrast, *C. minutissima minutissima* usually has a high percentage of its lobules inflated and bent against the lobes; such lobules are about three-fourths to four-fifths the area of the lobes (Fig. VI: 1, 3).

(2) The lobes in *C. minutissima myriocarpa* are somewhat more ovate, and usually show a discrete apex, marked by a single cell (Fig. VII: 10); leaves with inflated lobules, furthermore, show 3–4 cells of the lobe distinct beyond the tip of the 2-celled apical tooth, and 4–5 rows of cells beyond the anterior margin of

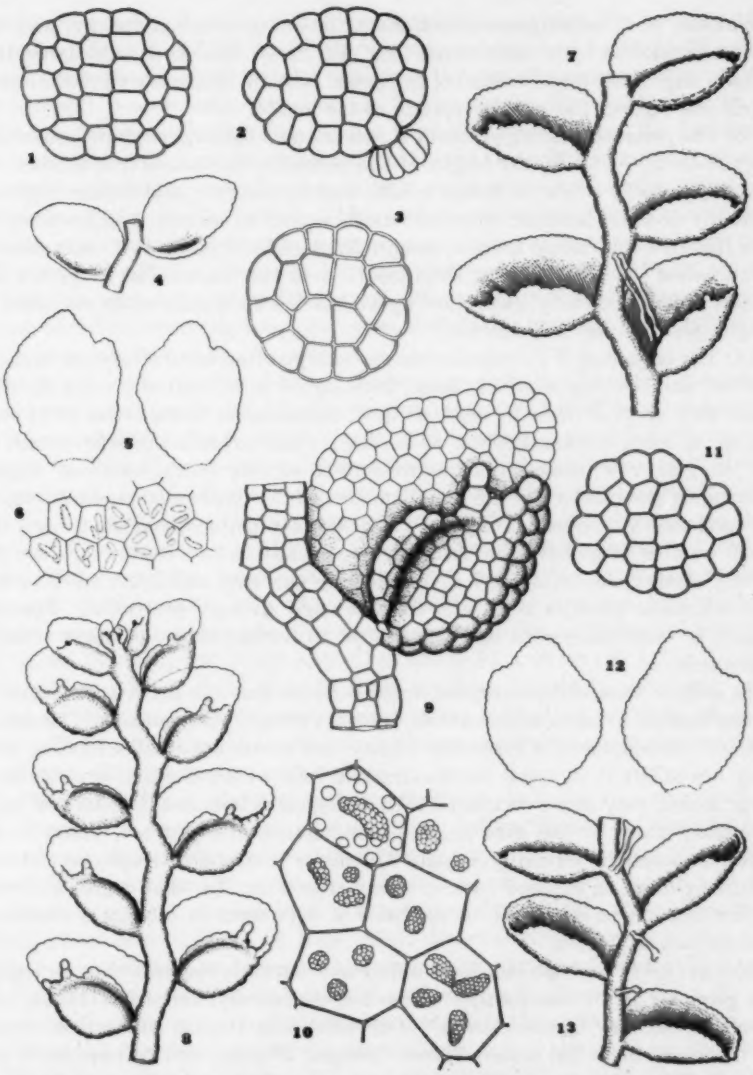


FIG. VIII. *Cololejeunea minutissima minutissima* (Sm.) Schiffn. 1. Gemma (× 210); 2. Gemma developing a secondary gemma (× 225); 3. Small gemma (× 500); 4. Postical view of shoot sector, bearing "explanate" leaves (× 55); 5. Two female bracts (× 55); *Cololejeunea minutissima myriocarpa* (Nees and Mont.) Schust. 6. Median cells, with oil-bodies stippled in (× 340); 7. Postical view of shoot-sector, with nearly "explanate" leaves (× 92); 8. Postical view of "normal" shoot-sector, from plant growing admixed with that in Fig. 7 (× 92); 9. Leaf of plant of type in Fig. 8 (× 240); 10. Median cells, with oil-bodies and (upper cell) chloroplasts (× 750); 11. Mature gemma (× 225); 12. Female bracts (× 55);

the lobule. In *C. minutissima minutissima*, the lobe is rounded distally, with the apex not marked by a distinct cell (Fig. VI: 1, 3); the lobule is so large that usually only 2 cell-rows (or less) of the dorsal lobe are distinct beyond the apical tooth and beyond the anterior margin of the lobule.

(3) The perianth-bearing plants of *C. minutissima myriocarpa* show bracts that vary from *ca.* ½ to ⅗ the length of the perianth; the bracts are, further, essentially broadly ovate, with the lobule scarcely discrete, and with a slight or virtually no sinus between lobe and lobule, as well as with no keel between the two (the lobe and lobule lying in essentially the same plane). In *C. minutissima minutissima* the perianths are little longer than the bracts. The latter are distinctly indented distally, each showing a sinus descending for up to one-third its length, and the keel is distinct.

(4) The oil-bodies of *C. minutissima myriocarpa* often occur singly (or in pairs) per cell, and then are relatively large, from 3.5 x 6 to 4.5 x 10 to 4 x 12 μ; in other cases they are 3–5 per cell, much as in *C. minutissima minutissima*—but some leaves, at least, constantly show oil-bodies 1–2 per cell in many cells, except for the marginal row; these oil-bodies are formed of very small, relatively slightly protruding globules *ca.* 0.5–0.8 μ in diameter. In *C. minutissima minutissima*, the oil-bodies always appear to number (2) 3–5 or 4–6 per cell, and are formed of a small number of globules (in surface-view, usually in two rows); they are distinctly smaller and *ca.* 3–5 x 7 μ, occasionally narrower and 2–2.5 x 7–9 μ, with the individual globules 1–1.5 μ in diameter and strongly protruding. The constancy of these differences must be subject to further study of longer series of specimens.

In spite of these differences, the writer believes that it is necessary to consider *C. myriocarpa* at most subspecifically distinct from *C. minutissima*. The almost constant development of explanate lobules (and somewhat smaller lobules, when they are inflated) *vs.* usual development of inflated lobules that are relatively large in size, may prove correlated with ecological differences. The former taxon is usually more or less mesophytic—being found in evergreen, dense forests where atmospheric humidity is high. The latter is strongly xerophytic at times, occurring often on exposed bark in sunny situations. To what degree the other differences can be explained on the basis of differences in ecological conditions is unknown at present.

Evans (1911) has also indicated differences between the two taxa as regards the gemmae. In "*C. myriocarpa*" these are, supposedly, formed of 15–16, more rarely 14 cells; in "*C. minutissima*" of up to 34 cells. In that connection, a study of the *myriocarpa*-like material from Georgia, Florida, and Mississippi is pertinent. These specimens, with totally explanate lobules, serve to connect "typical" "*C. minutissima*" with "*C. myriocarpa*." In the Mississippi and Florida plants, the gemmae are variously from 16–20-celled at maturity (*RMS 20381*) or from 16–24-, occasionally 26-celled at time of dehiscence (*RMS 22837b*); in

13. Sector of shoot, postical view (× 60). (Fig. 1, Hillsborough R., Fla., *Schuster*; 2, Florida, *Schuster 22873b*; 3, Mississippi, *Schuster 20381*; 4–5, Georgia, *Schuster 31480*; 6–9, Monroe Co., Fla., *Schuster 31759*; 10, Paradise Key, Fla., *Schuster 22558*; 11–13, Cuba, *Britton et al. 4645*).

none of these plants do the gemmae ever attain a larger size. By contrast, the plants from Georgia (*RMS 31480*) show gemmae formed of up to 34–38 cells. These plants, though provided with explanate leaves and bracts much as in "*C. myriocarpa*," possess cells each bearing 3–5 moderate-sized oil-bodies, as is typical for "*C. minutissima*." It is evident from the foregoing that the leaf-form and bract-form do not serve to separate sharply the two entities, and that plants occur with gemmae whose cells, at maturity, are intermediate between what are regarded as typical for the "species." However, the writer has found a correlation between many-celled (28–34 cells) gemmae and smaller and more numerous oil-bodies per leaf-cell, and, inversely, between fewer-celled gemmae (16–24, rarely 26) and few, very large oil-bodies per cell. This suggests that some genetic difference occurs between the two types, even though this may not prove sufficient for the maintainance of species.

The differences in number of cells of the gemmae given by Evans do not appear to hold any better for the West Indian material than for that of the southeastern United States. For instance, in the abundant epiphyllous material of "*C. myriocarpa*" (det. Evans), from Cuba (*Britton, Britton & Wilson 4645*, Hoyo de Manicaragua, Santa Clara, 1910) I find that the bract and leaf-characters are identical with the explanate-leaved plants from our southeast, and the gemmae are also identical. The vegetative shoots possess somewhat narrowly ovate to broadly elliptical lobes (*ca.* 300 μ long x 190 μ wide), with the lobule narrow and a mere rectangular fold (*ca.* 220 μ long x 80 μ wide) that is barely separated by a shallow and obtuse notch from the lobe. The gemmae at maturity are formed of from 25 cells (then 75 x 95 μ) to 27–29 cells (then either 75 x 90 or 100 x 115 μ); the larger gemmae, like some of those from the southeastern plants, are clearly two cell-layers thick medially. Occasional gemmae are formed, at maturity, of only 20 cells. One such gemma (82 x 75 μ) showed development of a marginal secondary gemma, at right angles to its surface.

On the other hand, the slightly gemmiparous plants of "*C. myriocarpa*" (det. Evans; from near Santiago, Oriente, Cuba, *Britton, Britton & Cowell 12618*) show gemmae more nearly approaching those described by Evans for "*C. myriocarpa*." They vary from 16-celled (56 x 46 μ) to 17- or 18-celled (64–68 x 54–60 μ). Connecting these two extremes is a specimen from Puerto Rico (Desecheo Island, 1914; *Britton, Cowell & Hess 1610*), determined by Evans. In this the gemmae are abundant and vary at maturity from 18-celled (60–64 x 52–55 μ) and 19-celled (70 x 58 μ) to 20-celled (60 x 68 μ) or even 22-celled (75 x 68 μ). This wide diversity in form of the gemmae suggests that differences in age, or environmental factors, may influence the ultimate size of the gemmae, and that no clear difference exists between "*C. myriocarpa*" and "*C. minutissima*" on this basis.

C. minutissima myriocarpa appears to be exceedingly similar to the recently described *Physocolea myriantha* Herzog (Memor. Soc. pro F. Fl. Fenn. **27**: 102 fig. 47, 1951), which I would regard as a subspecies of *C. minutissima*. The only difference cited by Herzog that would allow a separation *of Physocolea myriantha* from the *C. myriocarpa-minutissima* complex are: (1) the slightly larger cells, 20 μ at the apex, 20 x 20–25 μ distally, 18 x 35 μ at the base; (2) the slightly weaker

dorsal keel of the 5-carinate perianth. It must be remembered that the cell size in *C. minutissima-myriocarpa* is quite variable, the cells near the apex averaging up to 18 x 22 μ (which is considerably above the 12 x 18 μ given by Stephani). All the other minor "differences" cited as diagnostic of *Physocolea myriantha* appear to recur also in the very polymorphic *C. minutissima-myriocarpa* complex. Herzog emphasizes that if the two are united, a singular distribution pattern will result. However, a parallel case occurs in *Lejeunea bullata*, which is represented in South Africa by the exceedingly similar *L. ocellifera* (= *Microlejeunea ocellifera* Arnell), again a vicarious type very doubtfully distinct from *L. bullata*. The eagerness of botanists to describe each of these entities as new species has served merely to obscure these phytogeographical affinities.

In this same complex belongs the African *C. dissita* E. W. Jones (1954), in which the cell size is reported as falling within the range of the plants here assigned to *C. myriantha*. However, in *C. dissita* the inflated lobules are only about 0.3–0.35 times the area of those of the lobe. Unless "fruiting" characters will prove to demonstrate the specific distinctness of *C. dissita*, it is doubtful whether this can be maintained as a species distinct from the plants here assigned to *C. minutissima myriocarpa*.

Cololejeunea subcristata Evans

Cololejeunea subcristata Evans, The Bryol. **20**: 20, pl. 2, f. 5–14, 1917; Evans, The Bryol. **41**: 81, 1938; Frye and Clark, Univ. Wash. Publ. Biol. **6**: 885, 1947.

Plants delicate, *like a small form of Leptocolea cardiocarpa*, pale yellowish green, occurring mostly as scattered plants or in very small, closely appressed, flat patches; shoots *ca.* 780–850 μ wide. Stems, prostrate, 50–55 μ in diameter, irregularly and often freely branched, the branches at nearly right angles to stem, often with somewhat smaller leaves. Leaves typically slightly imbricate, virtually flat, appressed, spreading widely (55–85°). *Lobes ovate*, often arching across stem dorsally, with antical margin rather strongly and evenly arched, the postical margin nearly straight, attaining a length of 400–450 μ and width of 250–300 μ on main shoots, narrowed to an obtuse, barely subacute or narrowly rounded apex, *devoid of hyaline papillae*, 14–18 cells wide, the margin entire to vaguely crenulate due to slightly projecting cells. *Lobule unusually small* (length *ca.* 0.33–0.4 × the lobe), *but usually well-developed and inflated, its surface smooth*, with keel rather strongly arched, but posterior margin not notched, or barely so, at juncture of keel and free lobe; lobule *ca.* 160–190 μ long x 85–90 μ wide, the free margin involute up to the apical tooth; *apical tooth of two cells in a row*, the hyaline papilla near proximal base of tooth (but slightly to distinctly entally displaced); proximal tooth obtuse, low, barely distinct, separated from apical tooth by a single cell; sinus between apical tooth and keel shallow, 1–2 cells broad; keel with cells slightly convex, but never conically produced; *stylus reduced to a hyaline papilla*. Cells uniform (no ocelli), weakly *convex but never conically produced anywhere on leaf*; cell-walls thin to barely thickened, with discrete, small to rather large trigones and occasional intermediate thickenings of the longitudinal walls; marginal and apical cells *ca.* 14–17 μ, of leaf-middle up to *ca.* (15) 18–22 x (18) 20–25 μ; oil-bodies small and usually oval to fusiform, *ca.* 1.8–2 x 4–6.5 to 3 x 7.5 to 4.5 x 9 or 3 x 15 μ, occasionally subspherical and (2) 3–4 μ, *distinctly and relatively coarsely segmented* (usually of only 1–2 rows of individually protruding globules, each *ca.* 1–1.5 μ), (3) 4–8, rarely 10 per cell, averaging barely or not larger than chloroplasts. Asexual reproduction by discoid gemmae, broadly orbicular, *ca.* 40 x 35 μ, *formed of 16 cells, the margins subentire*, lacking organs of attachment.

Autoecious. *Female inflorescence usually on a strongly abbreviated branch*, more rarely on an elongate shoot, often with only 1–2, reduced, atypical leaves below the bracts, innovating on one side (the innovation usually elongate, sometimes fertile again but usually sterile or

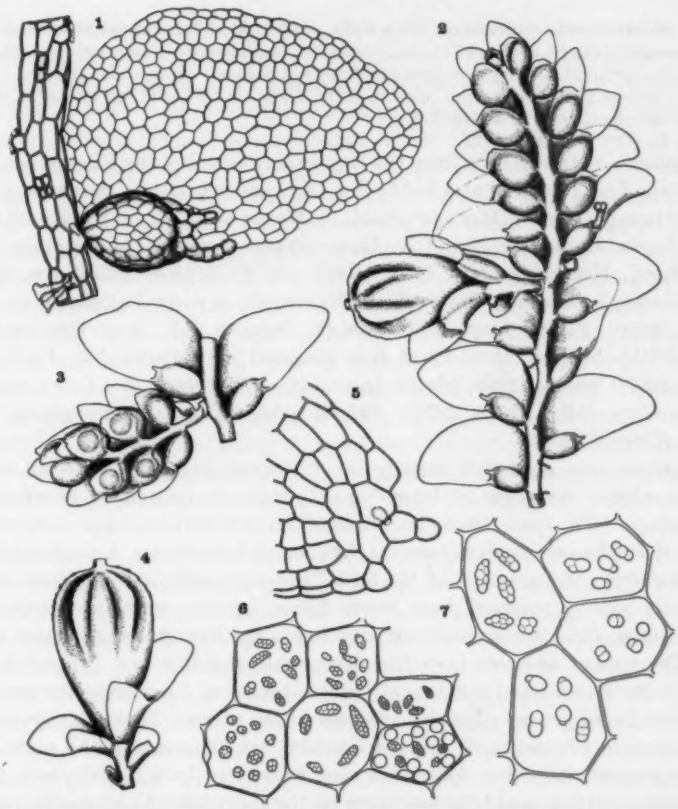


FIG. IX. *Cololejeunea subcristata* Evans. 1. Shoot-sector, postical view, with leaf (× 130); 2. Fertile plant, with androecium of leading shoot, a rotifer in lobule (× 45); 3. Shoot-sector, postical view, with small-type androecium of lateral position (× 48); 4. Perianth-bearing, short, lateral branch (× 45); 5. Apex of lobule, the hyaline papilla indicated (× 300); 6. Median cells (× 620); 7. Median cells (× 890). (Fig. 1, Paradise Key, *Schuster 22592*; 2–4, Hammock on Loveland Rd., Dade Co., Fla., *Schuster 22666a*; 5–6, Long Key Pineland, Dade Co., Fla., *Schuster 22010*; 7, Long Key Pineland, Fla., *Schuster 22032*).

♂); ♀ bracts obliquely spreading, somewhat smaller than vegetative leaves, complicate, the lobe similar to that of leaves but narrower, occasionally obovate rather than ovate, 330–380 μ long, up to 450–500 μ long x 250–300 μ wide, narrowly rounded or subacute at apex, the lobule ovate to oblong, 180–225 μ long, occasionally to 300 μ x 120–200 μ wide, the apex rounded to subacute, broad, sometimes emarginate (with hyaline papilla in sinus). Perianth obovoid, *ca.* 675–750 μ long x 410–460 μ wide, the apex rounded to narrowly truncate, shortly beaked, sharply 5-keeled for fully 0.5–0.65 × its length, the keels vaguely and irregularly cristate or crenulate (in part with 2-celled teeth), but perianth otherwise smooth. Androecia either terminal on a main branch (which often bears below it the short ♀ branch), then 360 up to 650–720 μ wide and formed of 3–5 or more pairs of imbricate bracts that are often little smaller than normal leaves, differing from them only in the smaller lobes and larger, more ventricose lobules (whose apices are truncate rather than bidentate); occasionally androecia situated like archegonia: on short, reduced lateral branches (then with bracts only *ca.* 0.5 ×

as long as leaves and androecia *ca.* 350 μ wide, consisting of 3–4 pairs of imbricate bracts, with strongly reduced lobes and strongly inflated, large lobules); androecia in either case apparently terminal and not proliferating; bracts apparently always monandrous.

Type: Hattie Bauer Hammock near Modello, Dade Co., Florida, on leaves of the fern *Tectaria minima* (*Small & Mosier 5327*).

Distribution: Known only from the tropical lower end of the Florida peninsula, from Dade Co.; probably also in Monroe and Collier Counties. DADE CO. (Hattie Bauer Hammock, near Modello [*Small & Mosier 5327, type*; MacFarlin 1914]; Nixon-Lewis Hammock, *Small & Mosier 6008*; Royal Palm Hammock [Paradise Key], Everglades Ntl. Park, *RMS 19917, 33850d, 22592* p.p. [among *Rectolejeunea berteroana*]; Palma Vista Hammock, n.w. of Paradise Key, *RMS 22078, 22072, 22073*; Costello Hammock, Newton Rd., near Hainlin Drive, *RMS 22945*; Section 24 of Long Key pineland, Everglades Ntl. Park, *RMS 22053, 22010* [*plate*], *22029* [plate]; hammock on Loveland Road, 5–6 mi. w. of Florida City, *RMS 22571, 22764, 22666a* [*plate*]; Timms Hammock on Bauer Drive, *RMS 33701d*).

A rare species, occurring usually in very small quantity, with all but the western edge of its range in danger of extinction by real estate developments.

ECOLOGY.—The type (from the leaves of *Tectaria minima*) and isotype (from leaves of *Trichomanis krausii*) are epiphyllous on fern leaves. A single additional collection from living leaves of the fern *Tectaria heracleifolia* (*Schuster 33701d*) has been seen; associated here were *Aphanolejeunea evansii, Caudalejeunea lehmanniana, Cololejeunea myriocarpa-minutissima* intergrade, *Lejeunea minutiloba*. The species has also been found in small quantity, but typical development, in the fluted basal portions of the leaf-blades of *Sabal palmetto*; associated here were *Leptolejeunea elliptica, Aphanolejeunea evansii, Leptocolea cardiocarpa, Caudalejeunea lehmanniana, Diplasiolejeunea rudolphiana* and the moss, *Taxithelium planum*. All other collections seen were from bark, particularly that of dead lianas or twigs and branches lying on the most humid and shadiest portion of the hammock floors, or on twigs and small branches of trees, occasionally on the bark of smooth-barked trees (such as *Guettarda scabra, Elaphrium simaruba, Eugenia* (*Annamomis*) *simpsoni, Lysiloma bahamensis*). The occurrence, most frequently, on fern leaves around limesinks, or on shaded, moist dead twigs and lianas lying on the hammock floor, emphasizes the extreme restriction of the species, apparently to areas with constantly diffuse light, and a constantly very low saturation deficit. On dead twigs the species occasionally occurs alone; on lianas it may be associated with other delicate corticoles having a very slight or no ability to compete, such as *Leptolejeunea elliptica, Cololejeunea minutissima, Leptocolea cardiocarpa* and *Diplasiolejeunea rudolphiana*. By contrast, on bark it is found with *Lejeunea* cf. *longifissa, Cololejeunea minutissima, Rectolejeunea brittoniae, Leptolejeunea elliptica, Caudalejeunea lehmanniana*, rarely *Aphanolejeunea ephemeroides, Rectolejeunea berteroana, Microlejeunea laetevirens*.

DIFFERENTIATION.—The totally smooth cells of the leaves separate *C. subcristata* from all of its regional congeners, except *C. minutissima, C. setiloba*, and the most mesic extremes of *C. diaphana*. It differs from the first of these three related species at once in the ovate leaves, with very small lobules that show no

tendency to become explanate, even though the 2-celled apical tooth of the lobule emphasizes its relationships to that species. The ovate, somewhat pointed leaves suggest *C. setiloba* and *C. diaphana*. However, the almost uniformly inflated lobules serve to separate the species from both of these (in *C. setiloba* the lobules are all reduced and non-inflated; in *C. diaphana* the majority of lobules are essentially elobulate). The 16-celled gemmae are quite distinct from those of all three of the aforementioned species, which typically have gemmae of 20–22 cells (or more, in the case of *C. minutissima*). The facies of the species is most nearly similar to that of *C. diaphana*, and the lobulate leaves of the latter may be virtually identical in form with those of *C. subcristata*, averaging barely narrower and somewhat more pointed. As a consequence, the discrimination of the two must be attempted with care. In *C. subcristata* the leaves are never dimorphic, and mature shoots show no elobulate leaves; furthermore, the leaf-cells are never conically produced or tuberculate. By contrast, *C. diaphana* shows strongly dimorphic leaves, with many or most elobulate, while the marginal cells of the lobe (and often those of the keel and of the rest of the lobe) are more or less conically tuberculate. *C. subcristata* is also among the larger of our species (mature shoots 780–850 μ wide), while *C. diaphana* is rarely over 500 μ wide.

In the large size, form of the lobule and of its apical tooth, the ovate leaf-form, the form of the cells (with small but discrete trigones and occasional intermediate thickenings), and of the oil-bodies, as well as of the androecia and perianths, *C. subcristata* very closely approaches the smaller forms of *Leptocolea cardiocarpa*. The latter, as is emphasized elsewhere, often virtually lack the hyaline, finger-like terminal cells of the lobes, and then closely approach the present species. Consequently, sterile plants of *C. subcristata* that lack the 16-celled gemmae must be separated with extreme care from *Leptocolea*. The student will find that, in particular, the initial phases of *Leptocolea*, produced from gemmae, and occurring as isolated plants on various leaves or on bark, show such a close similarity to *C. subcristata* that they are virtually inseparable. It should be kept in mind that the cells of *C. subcristata* are larger (averaging 20–23 μ wide in the leaf-middle, *vs.* 18 μ in *Leptocolea*), and that no leaves of *C. subcristata* ever bear hyaline terminal papillae. The lobules of *C. subcristata* are also relatively small (*ca.* ⅓ the lobe length), while those of *Leptocolea* average fully one-half the lobe-length. When gemmae occur, the 16-celled gemmae of *C. subcristata* immediately separate it from *Leptocolea*, with many-called gemmae.

Cololejeunea setiloba Evans

Cololejeunea setiloba Evans, The Bryol. **16**: 51, 1913, figs. 1–7; Evans, The Bryol. **41**: 81, 1939.

Yellowish to (rarely) dark green, growing in flat, depressed mats; shoots 550–750 μ wide. Stems 45–50 μ in diameter, becoming copiously and irregularly, pinnately branched, the branches widely spreading, sometimes becoming elongated and similar to the main axes but usually short and bearing the sex-organs. Leaves distant to barely contiguous, the lobe rather to quite widely spreading (60–80°); lobe plane or very slightly convex, *ovate*, from a strongly constricted base, gradually narrowed towards the *obtuse or narrowly rounded apex*, varying from (260) 350–370 μ long x (160) 225–230 μ, occasionally 400 x 300 μ, the *margin rather strongly crenulate from projecting, rounded cells; lobule uniformly vestigial, reduced* to

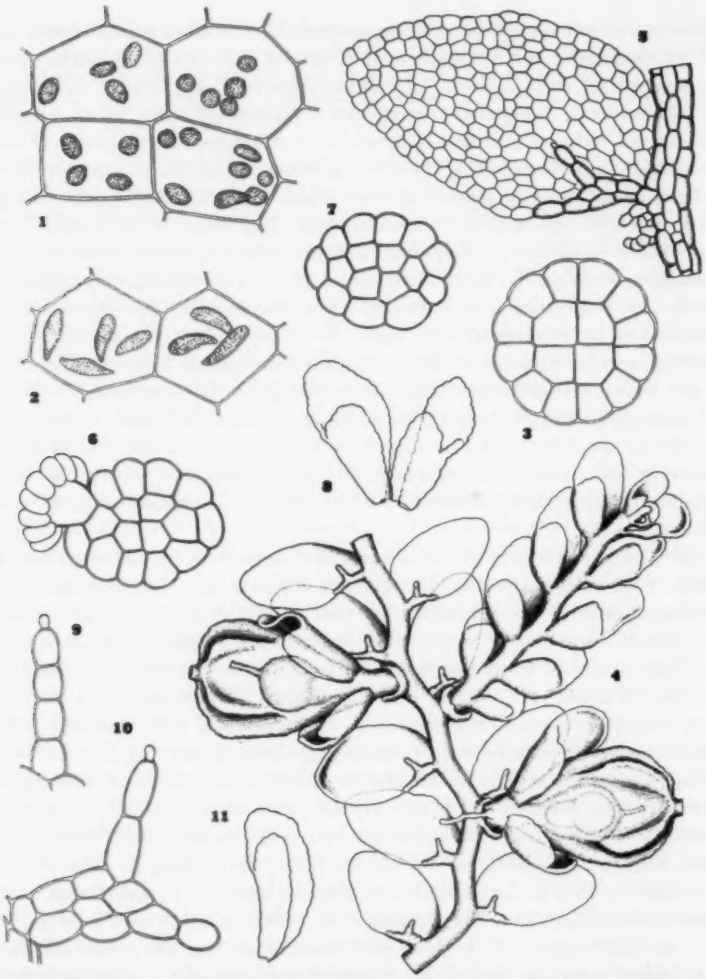


FIG. X. *Cololejeunea setiloba* Evans. 1. Median cells (× 860); 2. Median cells (× 1050); 3. Cross-section of seta (× 295); 4. Postical view of plant with androecium, two perianths (× 64); 5. Leaf from plant, with "Anlage" of branch (× 135); 6. Gemma, with secondary gemma (× 320); 7. Gemma (× 320); 8. Female bracts (× 75); 9. Apical tooth of lobule (× 300); 10. Lobule with apical tooth (× 300); 11. Female bract (× 75). (Figs. 1–4, Hillsborough State Park, Florida, *Schuster 33921a*; 5–11, Louisiana, *Svihla*).

a narrow basal fold 2 or 3 cells wide and 2–3 cells long (*ca.* 30 x 75 μ), with a straight, slightly convex or slightly concave keel, the free margin *terminating in a single tooth* typically *uniseriate and 2–4 cells long*, terminating in the hyaline papilla (occasionally, tooth 2 cells wide at base) length of lobule from base to apex of apical tooth (90) 110–125 μ; *stylus vestigial*, a mere slime papilla. Cells extremely leptodermous, virtually devoid of trigones, without intermediate thickenings, *ca.* 15 μ along margins, 15–18 × 17–23 μ wide medially, becoming somewhat larger (to 15–18 x 21–30 μ in the middle of the base), tumid and convex but *never*

conically elevated; oil-bodies finely papillose-segmented, 3–4 μ and spherical to 3.5–4 x 5–6 μ to 2.5–3 x 7–9 μ and ovoid to ellipsoidal to parameciform, occurring (3)4–8 per median cell. Asexual reproduction by regularly crenulate to discoid gemmae, varying from 16-celled and 50 x 70 μ to 19–22-celled and 60–75 x 75–90 μ; gemmae crenulate, *lacking organs of attachment, developing from the antical surface of the lobe.*

Autoecious. Female inflorescence on either an elongated branch or an abbreviated one (which may lack vegetative leaves), sometimes innovating on one side, the innovation short and sterile or again floriferous, often without innovations. Bracts suberect at first, with maturation of the perianth becoming obliquely spreading, complicate, but keel merely crenulate, not winged, the lobe similar to leaves but usually narrower and shorter, often narrowly oblong and more broadly rounded at the apex than on vegetative leaves, *ca.* (100)140–150 μ wide x (180–280)300–350 μ long (with lobule (80)90–95 μ wide x (135–160)200 μ long); lobule narrowly oblong to obovate, free for 0.2–0.3 × its length, usually rounded (rarely subacute) at apex; margins of lobe and lobule crenulate like leaves. Perianth obovoid, *ca.* 350–450 μ long x 250–350 μ broad, sharply 5-carinate to about the middle, the keels faintly roughened from rounded, protuberant cells, rarely narrowly winged, the apex rounded to truncate, shortly beaked, the base after fertilization shortly stipitate. Male inflorescence usually apical on a short, lateral branch, sometimes on a leading elongate branch, loosely spicate, *ca.* 325–350 μ wide; bracts most often in 3–6 pairs, loosely complicate-bilobed *with subequal lobes* or with dorsal lobe considerably larger, both lobes rounded or obtuse to subacute distally; usually diandrous. Capsule *ca.* 150 μ in diam.; spores greenish, delicately verruculose, 13–16 μ in shorter diameter, x 30–42 μ in length; elaters *ca.* 5–7 μ wide; seta of 4 inner, 12 outer cell rows, 80–90 μ in diam.

TYPE: Sanford, Seminole Co., Fla. (*S. Rapp, 27*), on bark of *Ilex glabra*.

DISTRIBUTION.—With a restricted range, involving (as far as known) only the "Oligocene Island" region of central Florida and the southern portion of Louisiana. The range is strikingly similar to that of the North American range of the fern, *Blechnum occidentale* L. (see Brown and Correll, 1942).

Florida: SEMINOLE CO. (Sanford, *Rapp 27, 12, 59*); HILLSBOROUGH CO., Hillsborough R. State Park, *RMS 33921a*, p.p.; plate!); HIGHLANDS CO., n. edge of Highlands Hammock State Park, w. of Sebring, *RMS*); HARDEE CO. (n.e. of Crewsville, *RMS*). Also reported from Desoto and Polk Cos., by Redfearn (1952). **Louisiana:** Stinking Bayou, near Akers (*Pennebaker* !); Avoca Island (Svihla, 1939).

ECOLOGY.—Perhaps the most mesophytic of our species of the genus, occurring in swamps or in humid, shaded hammock forests, lying along streams or rivers. The occurrence of the species is more closely bound up with the presence of standing or running water than that of any other regional species of the genus. The plants may occur on decaying logs at the edges of low, shaded, intermittent rivulets (as at Hillsborough R.; there with *Aphanolejeunea evansii*, *Lejeunea glaucescens* and *cladogyna*, *Ceratolejeunea laetefusca* and *Cheilolejeunea rigidula*, *Fissidens radicans*). They occur, however, more often at the bases of trees in swamps and very wet hammock, only a few inches above standing water, chiefly at the bases of *Taxodium distichum* and *Acer rubrum* (Highlands Hammock State Park), but also at the bases of the shrubby *Ilex glabra* and *Myrica cerifera* (Sanford, Florida), and at the bases of *Magnolia virginiana* in an open swamp forest (Hardee Co.). In deep, wet swampy hammocks, the plant may occur on the petioles of *Sabal*, the palmetto (Louisiana).

DIFFERENTIATION.—*C. setiloba* is very easily identified on the sole basis of the vestigial, short lobules that are apparently uniformly terminated by an elongate

apical tooth 2–4 cells long. No other species of the genus, at least from our region, ever possesses a lobule approaching that of this species.

The crenulate, quite unspecialized gemmae, devoid of swollen slime-cells ("organs of attachment"), the total lack of conical elevations of the leaf-cells, the rounded or obtuse leaf-apices, and the form of the female bracts strongly suggest *C. minutissima*, which also often lacks inflated lobules. In this species, however, the lobules are then reduced to an ill-defined, elongate fold (more than 0.6 times the lobe-length), which is obtusely terminated.

C. diaphana may possibly be confused with the present species, since plants of the former may occur with all, or almost all, leaves with vestigial lobules. However, *C. diaphana* has different gemmae (with 3 slime-cells), always shows at least a few lobulate leaves, and has the lobules of elobulate leaves reduced to a mere basal vestigy of 1–2 cells, quite lacking all trace of an apical tooth; it also has a marked tendency towards production of conically elevated cells.

Similar lobules occur in other regional Lejeuneaceae. For example, various species of *Lejeunea* (*L. minutiloba*, *L. glaucescens*, *L. cladogyna*, etc.) and *Stylolejeunea* (*S. spiniloba*, *S. pililoba*) produce vestigial, non-inflated lobules, each ending in a more or less attenuate apical tooth, bearing the hyaline papilla at its apex. Such lobules are to be regarded as derivative, reduced types.

The filiform apical teeth of the lobules of *C. setiloba* are commonly 3–4 cells long in well-developed material. However, less robust plants occur (and freely develop perianths, see Fig. X: 4) in which the lobules are almost or quite uniformly tipped by a short tooth formed of only 2 superimposed cells (Fig. X: 10). Such plants rather closely approach lax, elobulate phases of *C. diaphana* in appearance; these may lack conically produced cells. In *C. setiloba* it is not rare to find a gemma which has produced, from one of its marginal cells, and at right angles to it, a secondary gemma (Fig. X: 6). This phenomenon has also been observed in the allied *C. minutissima-myriocarpa* complex, but not in any of our other species.

Cololejeunea macounii (Spruce ex Underw.) Evs.

Lejeunea (*Cololejeunea*) *macounii* Spruce ex Underwood, Bull. Torrey Bot. Club **17**: 259, 1890.

Cololejeunea macounii Evans, Mem. Torrey Bot. Club **8**(2): 171, pl. 22, fig. 1–8, 1902.

Plants in pale to yellowish-green, loosely depressed patches, or creeping singly; rather robust (shoots mostly 650–850 μ wide); irregularly, pinnately branched; usually with 1 subfloral innovation, which may be again fertile. Stems delicate, 70–80 μ in diam.; rhizoids locally rather common, arising in fascicles. Leaves uniformly lobulate, moderately imbricate, suberect to obliquely spreading (at a 35–55° angle with the stem), almost plane to distinctly convex. *Lobes asymmetrically oblong-obovate*, usually slightly falcate, *broadly rounded at apex*, 500–540 μ long x 340–360 μ wide, occasionally *up to 700 μ long x 450 μ wide*, the margin subentire to crenulate from tuberculate-protuberant marginal cells; dorsal margin evenly arched from a nearly erect base which does not arch across stem; postical margin forming a nearly continuous margin with keel, evenly convexly arched; *keel elongate*, strongly arched and inflated in appearance, distally crenulate-denticulate due to projecting cells, at apex somewhat sinuous-concave at juncture with lobe, but not notched. *Lobule large, uniformly well-developed*, ovate, strongly inflated near base and along keel, the *free margin nearly or quite plane and appressed to lobe*, from 300 μ long x 180–220 μ wide up to 400 μ long x 200–230 μ wide, *its length usually 0.55–0.6 × that of lobe*; apex of lobule obliquely

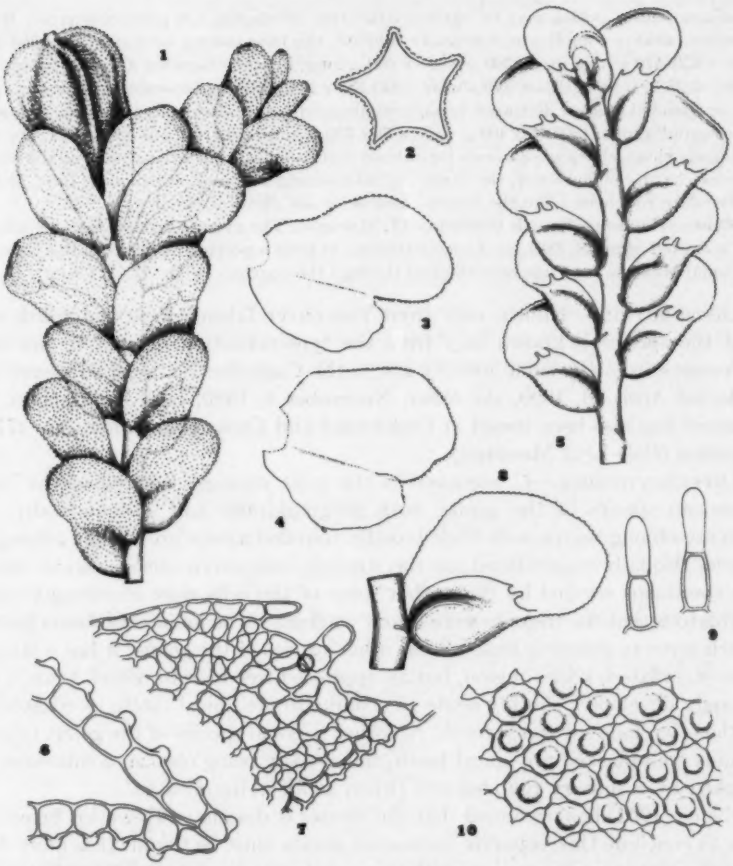


FIG. XI. *Cololejeunea macounii* (Spr.) Evans. 1. Fertile shoot, antical view (× 50); 2. Cross-section of distal one-third of perianth (× 58); 3–4. Female bracts (× 55); 5. Distal portion of sterile shoot, postical view (× 45); 6. Cross-section through one of the perianth keels (× 420); 7. Apex of lobule, strongly flattened, the lobule with preapical tooth unusually small (× 260); 8. Sterile leaf, postical view (× 70); 9. Two styli (× 420); 10. Median cells, antical view showing tubercles (× 420). (Figures all drawn from the type specimen.)

truncate, the *free margin with a marked, sharp, often slightly falcate pre-apical tooth*, usually 2–3 cells long, distinctly separated from the *2-celled apical tooth* which is constituted of 2 rounded cells; sinus between pre-apical and apical tooth subequal to sinus between apical tooth and keel; hyaline papilla ental, at base of apical tooth. *Stylus minute, commonly 2-celled*, occasionally of 3 superimposed cells or reduced to a hyaline papilla. Cells *strongly collenchymatous*, with thin walls and distinct to large, bulging trigones, and occasionally distinct intermediate thickenings; marginal cells *ca.* 10 μ; median cells from 11–16 x 13–18 μ up to 18–20 μ, subisodiametric; basal cells to 20 x 25 μ; external faces of cells of lobe somewhat convex, bearing a *thick-walled, rounded short-cylindrical, prominent thickening* except at leaf-base; *lobules with cells smooth. Asexual reproduction unknown.*

Autoecious? Gynoecia usually on leading, leafy branches, each bearing a single sub-

floral innovation (which may be again fertile after developing 4–6 pairs of leaves). Bracts suberect, weakly complicate, unequally bilobed, the lobe oblong-obovate, from 250–275 μ wide x 450–470 μ long up to 300 μ wide x 600 μ long, broadly rounded at apex; lobule free for 0.1–0.25 × its length, *ca.* 170 μ wide x 340–350 μ long, oblong to ovate or obovate, apiculate or rounded at apex. Perianth weakly stipitate with age, obcuneate in outline, rectangular-obovoid above, (300)350–400 μ wide x 700–750 μ long, subtruncate near apex, the beak extremely short, *sharply 5-carinate* for at least half its length, the carinae subequally strong, inflated, hardly compressed, the keels and intervening surfaces, except near base, sharply tuberculate-roughened like the leaves. Androecia not certainly known.[6]

TYPE:—Hastings, British Columbia (J. Macoun). The type specimen may be the first one collected (April 8, 1889, on *Acer circinatum*; at least a portion of this is in the Canadian National Museum, and has been studied through the courtesy of Dr. H. A. Crum).

DISTRIBUTION.—Known only from Vancouver Island. Frye and Clark state that the species is known only from the type collection. However, two other collections from the same locality are in the Canadian National Museum: one, collected April 20, 1890, the other, November 4, 1890, both by Macoun. The material has also been issued in Underwood and Cook, Hep. Amer. No. 177 (as *Lejeunea* (*Colo-Lej.*) Macounii).

DIFFERENTIATION.—*C. macounii* is the most strongly isolated of the North American species of the genus, both geographically and systematically. The obovate-oblong leaves with their broadly rounded apices are unique among our species. Equally unparalleled are the strongly collenchymatous cells: in some of the specimens studied by the author some of the cells were so strongly collenchymatous that the trigones were nearly confluent. The lobule also bears features which serve to isolate it from all our other species of the genus; it has a strongly convex, inflated, keelar region, but an appressed free margin, which bears a very strongly developed, sharply acute to acuminate pre-apical tooth, as conspicuous as the often inflexed apical tooth. No other regional species of the genus bears an equally well-marked pre-apical tooth, this usually being obtuse to subacute, and marked by a solitary rounded cell (when at all well-indicated).

Evans (1902) has presumed that the species is dioecious. However, before it is safe to conclude this, separate androecial plants must be found. It is more likely that the plants are autoecious, with the male bracts so slightly differentiated that they can hardly be distinguished from ordinary leaves. If dioecious, the type of inflorescence will serve equally to isolate the species from our other species of the genus.

Spruce (*in lit. ad* Underwood) compared the species to *Leptocolea cardiocarpa* (Mont.) Evs. and to *Cololejeunea platyneura* (Spruce). Any close affinity with either of these species is hardly possible. Evans (1902) in turn compared the species with *C. biddlecomiae*, a species bearing very few features in common, except the tuberculate cells, the 2-celled apical tooth of the lobule, and the distinct styli. However, the leaf-form, and much smaller size of the styli, the ♀ bracts,

[6] Part of the material studied by the writer bore spores, indicating that fertilization must take place. No trace of recognizeable ♂ bracts was found, however. Probably the ♂ bracts are essentially identical with the leaves, much as in *C. biddlecomiae*, and thus hardly recognizable except when with mature antheridia.

and the prominent, sharp pre-apical tooth serve to separate *C. macounii* from *C. biddlecomiae*.

A more evident relationship appears to occur with such east Asiatic species as *Cololejeunea denticulata* (Horikawa) Hattori. The latter species, from southern Japan (Yakushima) shares with *C. macounii* the form of the lobule, although the pre-apical tooth is less elongated, the 2-celled apical tooth, tuberculate dorsal lobe, obovate lobes, and strongly collenchymatous cells. *C. denticulata*, however, has an obsolete stylus, consisting only of hyaline papilla, narrower and more markedly obovate lobes, and cells with numerous intermediate thickenings. Although placed arbitrarily at the end of the Minutissimae, because of the rounded leaflobes, *C. macounii*, together with *C. denticulata* and a series of species from the Old World tropics, should be considered to represent a discrete section, the Sectio Denticulatae, restricted to species with collenchymatous, tuberculate cells and rounded, more or less obovate lobes.

MICROMYCES GRANDIS, A NEW MEMBER OF THE AQUATIC SYNCHYTRIACEAE

By Charles E. Miller

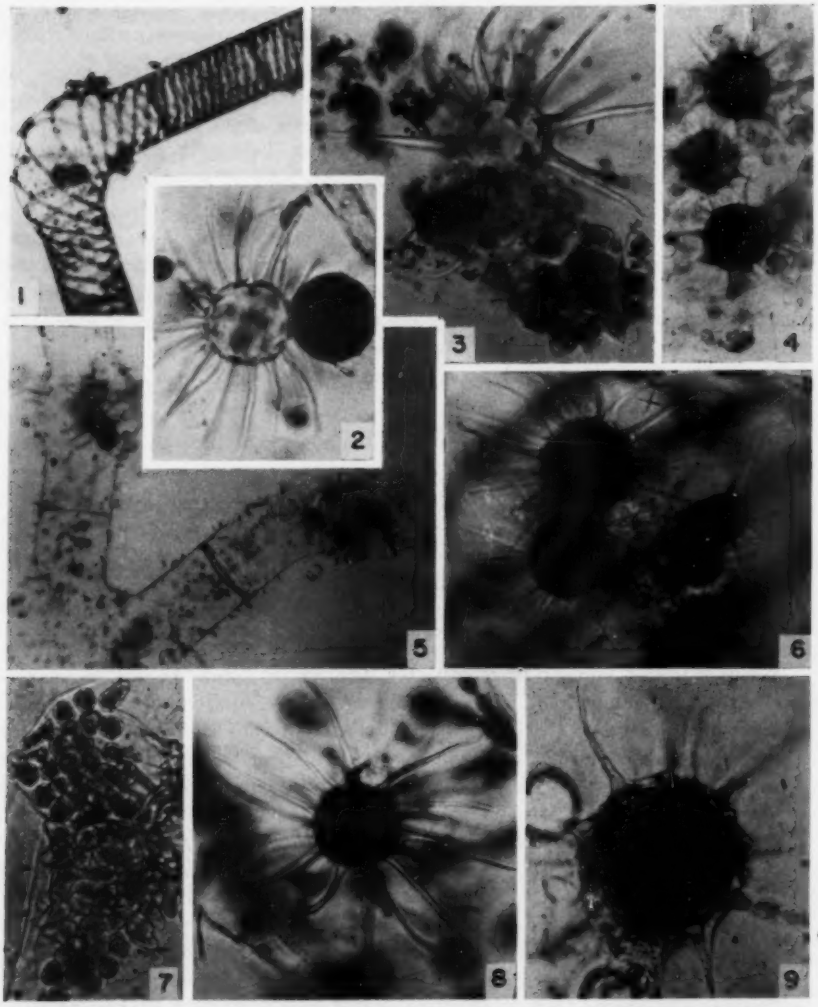
Department of Botany, University of North Carolina, Chapel Hill, North Carolina

While studying aquatic phycomycetes, the writer found, in one of his collections, several filaments of a large *Spirogyra* which exhibited peculiar geniculations. Upon closer observation, it became apparent that the cells showing this abrupt bending contained conspicuous spiny bodies, belonging to the genus *Micromyces*. This genus is an aquatic member of the family Synchytriaceae comprising a large number of obligate parasites on the flowering plants and Conjugales. The parasitic thallus is endobiotic, holocarpic, and at maturity is converted into either a prosorus, a sorus, or a resting body. Sexual reproduction, by conjugation of isogametes, occurs in some members of the family.

Dangeard established the genus *Micromyces* in 1888 for a "parasite of peculiar development" which he found in the alga *Zygogonium sp.*, and which he named *M. zygogonii*. Since that time, five additional species have been found: *M. spirogyrae* Skvortzow (1925), *M. Petersenii* Scherffel (1926), *M. longispinosus* Couch (1937), *M. laevis* Canter (1949), and *M. ovalis* Rieth (1950).

Micromyces grandis n. sp.

Prosorus 30.4–51.2 μ in diam., incrasso hyalino pariete, contecto multis (17–25) acutis spinis, 38.4–67.2 μ in long.; prosorus germinans in globosum sorum cum multis zoosporangiis. Zoosporangium pyramidatum, rotundo vel polygonio basi et truncato apice, 9.6–11.2 x 16.0–23.1 μ; zoosporangium generans in multas zoosporas scindendo, zoosporae ovoideae, uno globo olei et uno flagello posteriori,



FIGS. 1–9. *Micromyces grandis* in *Spirogyra sp.* FIG. 1. Filament of *Spirogyra sp.* showing infected and uninfected cells. Infected cell with two summer prosori. Note hypertrophied condition of infected cell. ×75. FIG. 2. Sorus just after germination from summer prosorus. ×323. FIG. 3. Sorus of summer prosorus which has burst apart releasing the sporangia. ×323. FIG. 4. Resting bodies (winter prosori). Note double wall. ×323. FIG. 5. Disintegrated filament of *Spirogyra sp.* Cells in upper and lower left contain summer prosori which have germinated to form sori, sporangia, and zoospores. Cell to the right contains five resting bodies. Note hypertrophied condition of host cells. ×75. FIG. 6. Several summer prosori clustered around host nucleus. Chloroplasts of host cell represented by dark bands. ×323. FIG. 7. Sporangia from sorus of summer prosorus. ×323. FIG. 8. Mature summer prosorus. ×323. FIG. 9. Winter prosorus highly magnified. Note double wall. ×698.

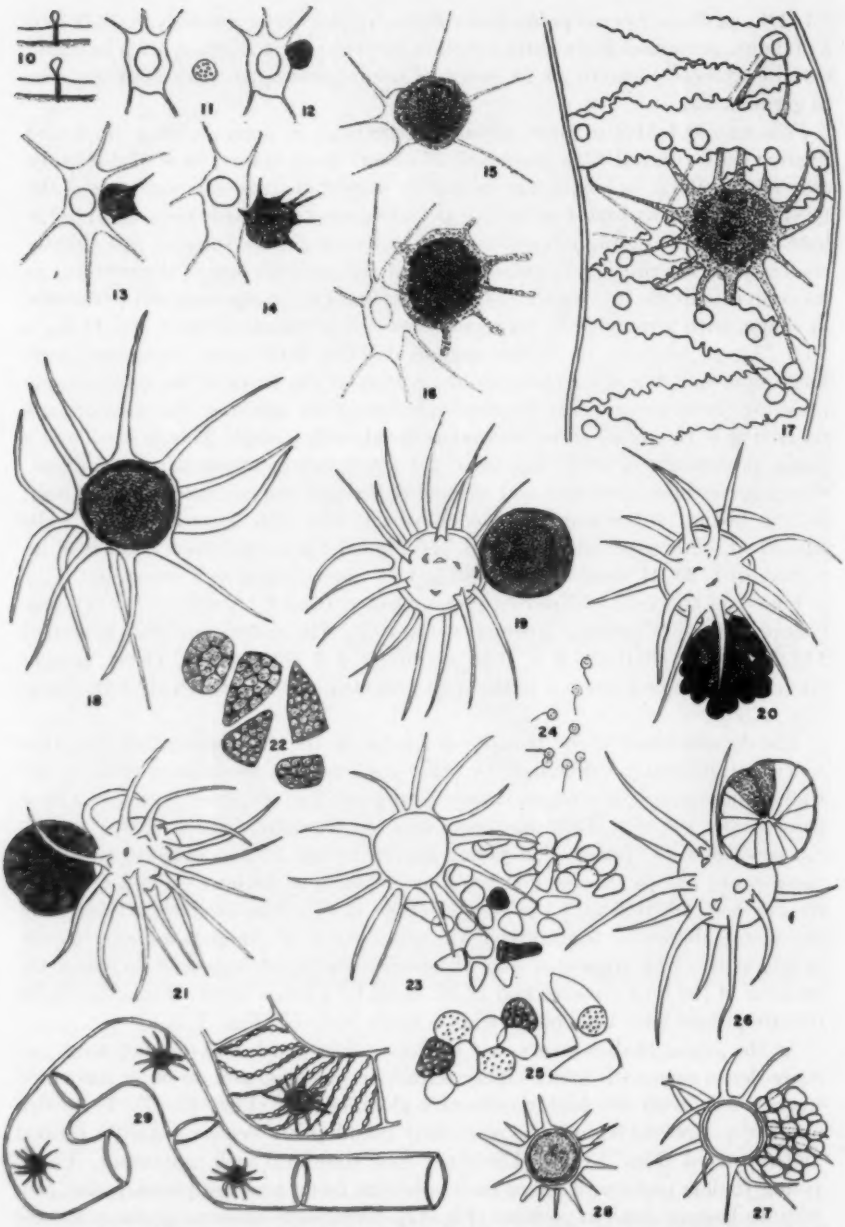
2.1–2.8 μ in diam. Sporae perdurantes flavae-virides vel aureae-fulvae, 16.0–32.0 μ in diam., parietibus incrassatis, exteriori corio ca. 1.4, μ interiori 1.1 μ in crass.; exteriori pariete contecto 20–24 brevibus spinis; perdurans spora fiens prosorus in germinatione.

Prosorus 30.4–51.2 μ (most about 40.0–48.0 μ) in diam., with a thickened hyaline wall, covered with many (17–25) long, sharp spines, 38.4–67.2 μ (most about 51.2–60.6 μ) in length; spines usually curved at their ends; contents of the prosorus with many highly refractive globules grouped towards the center; as the host cell becomes moribund, germinating to form a globose sorus at first slightly smaller than the prosorus; swelling to about $\frac{1}{5}$ again the size of the prosorus as its contents divide into many (33–54) zoosporangia; zoosporangium pyramidal in shape, with a rounded to polygonal base and a truncated apex, 9.6–11.2 μ x 16.0–23.1 μ; contents of zoosporangium dividing into many zoospores; soral membrane splitting along the lines of cleavage of the bases of the zoosporangia releasing them; occasionally the soral membrane not splitting, the zoosporangia remaining in the intact sorus; zoospores ovoid, with a single globule of oil and a single posteriorly directed flagellum, 2.1–2.8 (average about 2.3) μ in diam., escaping from the sporangia and swimming through the ruptured host cell wall; resting bodies, yellow-green to golden-brown, 16.0–32.0 μ in diam., the walls thickened, outer layer averaging 1.4, the inner 1.1 μ in thickness; outer wall invested with 20–24 short spines; resting body functioning as a prosorus.

Found in the cells of *Spirogyra sp.* collected from University Lake, Orange County, North Carolina, November 11, 1953. The individual cells measured 115.2–142.8 x 170.0–326.0 μ, and contained 4–6 chloroplasts. Other smaller species of *Spirogyra*, present in the same collection, were untouched by the parasite.

The development of the parasite is similar to the development of the other species of *Micromyces* described by other workers. The zoospore encysts on the wall of the host cell, leaving an empty spore case (Fig. 10) after its contents have passed into the cell. This was previously reported by Canter (1949) for *M. zygogonii* and *M. leavis*. The young thallus (Figs. 11–16) exhibits amoeboid movements, and by this method, and the streaming of the host cytoplasm, makes its way to a position near the nucleus (Figs. 6, 17). This seeming attraction of the young thallus to the nucleus was observed in *M. longispinosus* by Couch (1931, 1937), who suggested that the parasite actually appeared to usurp the position of the host nucleus, and in *M. laevis* by Canter (1949). From one to six mature prosori have been observed in a single host cell (Figs. 1, 5, 6).

As the young thallus grows, one is able to distinguish two distinct zones: an inner dense zone with many highly refractive globules, and an outer amoeboid hyaline zone with few highly refractive globules in it (Figs. 15–17). From this outer or peripheral region, one sees many pseudopodia being constantly formed and retracted (Figs. 13–16). The inner zone shows no such movement. As the young thallus matures it takes on a spherical form, and the pseudopodial projections become fixed in position (Fig. 17). Eventually these projections assume the form of more or less rigid spines. These are the spines of the mature thallus, the prosorus (Figs. 6, 8, 18).



FIGS. 10–29. *Micromyces grandis* in *Spirogyra sp.* FIG. 10. Penetration of host cell wall by zoospore. ×658. FIGS. 11–16. Development of parasite within host cell showing relationship of parasite to host nucleus. All stages ×304. Details of host cell omitted. Host nucleus to the

The time for maturation of the prosorus varies. Usually one expects mature prosori by the time the host cell has become more or less disintegrated. A distinct hypertrophy of the individual host cells was observed in almost all cases (Figs. 1, 5, 29). Usually the swelling in the lateral plane is so great that the cell wall bursts. Dangeard (1888, 1891) and Denis (1926), working with *M. zygogonii*, noted a definite hypertrophy in the host plants. Rieth (1950), while studying *M. ovalis*, reported a significant increase in host cell length, but a weak and seldom observed increase in lateral swelling. Canter (1949) reported no distinct hypertrophy of the host cell caused by *M. laevis*.

The prosorus germinates to form a spherical, thin-walled sorus (Figs. 2, 19). Couch (1931) found that the prosorus of *M. longispinosus*, prior to germination, was uninucleate as was the young thallus from which it developed. Curtis (1921), working with *Synchytrium endobioticum*, and Karling (1955a, 1955b) for *S. ranunculi* and *S. australe*, describe nuclear division as taking place after the germination of the prosorus to form the sorus, and Couch (1931) suggests that the same sequence of events may take place in *Micromyces*.

The sorus is then seen to divide into 33–54 or possibly more zoosporangia (Figs. 3, 7, 20, 21). The zoosporangia, when mature, absorb water and enlarge rapidly, rupturing the soral wall, and spreading out in an irregular mass. (Figs. 3, 7, 20, 23, 25). At times, the soral wall resists the swelling and the spores may then be discharged from their respective zoosporangia, leaving the sorus intact (Figs. 5, 26), as noted also by Couch (1931). Rieth (1950) shows that the sorus wall ruptures along the points of contact of the sporangia in *M. ovalis*, also observed in this fungus. Thus each segment of the sorus wall formed when it ruptures becomes the outer wall of a sporangium (Fig. 26).

After the formation of the sporangial walls, the contents of each sporangium are seen to form many zoospores. The zoospores usually escape from the sporangium through a single pore (Figs. 22, 25). The zoospore has a single posterior flagellum, and swims in a typical chytrid manner in the host cell, escaping through the ruptured host cell wall. According to Curtis (1921) and Couch (1931) the motile cells formed may behave as gametes and fuse in pairs.

Resting bodies which function as prosori are formed abundantly as the cultures age (Figs. 4, 5, 9, 27, 28). They are easily distinguished from the much larger

left: parasite to the right. Fig. 11. Very young parasite making its way toward the host nucleus. FIGS. 12–14. Parasite applied to host nucleus. Note pseudopodial projections. FIG. 15. Rapidly enlarging parasite applied to host nucleus. Pseudopodial projections withdrawn. FIG. 16. Maturing parasite. Note central dense portion and peripheral lighter portion of thallus. FIG. 17. Nearly matured parasite. Notice apparent usurpation of host nucleus. Pseudopodial projections of parasite seem to be connected to pyrenoids of host cell ×304. FIG. 18. Mature summer prosorus. ×304. FIG. 19. Sorus immediately after germination from summer prosorus. ×304. FIG. 20. Sorus of sporangia. Sporangia not discharged. ×304. FIG. 21. Formation of sporangia within sorus. ×304. FIG. 22. Formation of zoospores within sporangia. ×658. FIG. 23. Scattered sporangia most of which are empty. ×304. FIG. 24. Zoospores. ×658. FIG. 25. Discharged sporangia. Note discharge papilla. ×658. FIG. 26. Sorus of sporangia which has not burst apart. ×304. FIG. 27. Sorus of discharged sporangia of winter prosorus. ×304. FIG. 28. Matured resting body. Note double wall. ×304. FIG. 29. Filament and cells of *Spirogyra sp.* infected with parasite, showing the peculiar geniculations of the filament and the hypertrophied condition of the cells. ×71.

summer prosori. The contents are greenish-yellow to golden brown, the protoplasm is less dense, and no peripheral hyaline area is seen as is so typical of the summer prosori. Also, the resting bodies do not cause the host cell to become hypertrophied. A double wall is evident. The resting bodies are at first clustered about the nucleus, but later, as the host cell dies, they are found scattered throughout the cell (Fig. 4).

Throughout the period of study of this parasite, the writer was never able to obtain an abundance of material in any one collection, and hence it was necessary to take particularly good care of the material available. Collections of the host species of *Spirogyra* were brought into the laboratory and placed in small finger bowls. Each collection, in addition to the infected species, contained at least two smaller species of *Spirogyra* which were untouched by the parasite. With the aid of a dissecting microscope, it was possible to pick out with forceps the infected plants, and thereby establish several uni-algal cultures. When not being used for study, these cultures were kept in the algal culture room at temperatures ranging from 15 to 20° C.

For study under the compound microscope, the algal filaments were transferred to depression slides. When not being used, the depression slides, with living material in them, were kept in humid chambers made by placing moist filter paper in the lids of petri dishes. By this method several specimens could be handled with ease.

It was observed that a summer prosorus, after reaching maturity, took about three days to form and discharge zoospores. This time of development and subsequent discharge of zoospores seemed to be geared to the changing physiology of the host cell, i.e. as the host cell became moribund, the zoospores of the parasite became ready for discharge. That the zoospores reinfected the healthy host cells, was indicated by the gradually increasing number of infections per filament as compared with a newly collected filament. The cause of this difference was probably the confinement of the newly released zoospores to the filaments in the finger bowl. The effect of confinement on zoospore reinfection was further brought out by the fact that more parasites per cell occurred in such collections than in newly collected material.

Attempts were made by the writer to culture the host plant and the parasite. Bold (1942) lists several media for the cultivation of algae, and from these the following soil solution was chosen: Distilled water, 94.0 cc; stock soil solution, 5.0 cc; KNO_3 (5% aqueous solution), 1.0 cc. The stock solution was prepared by autoclaving one part of garden soil in two parts of distilled water at 15 pounds pressure for two hours. This decoction was cooled, decanted, and filtered, and the filtrate sterilized by autoclaving for 15 minutes at 15 pounds pressure.

Several 125 ml. flasks of this medium were prepared. Into each of these flasks were placed five filaments which had been previously dragged over sterile agar plates to remove as many micro-organisms as possible, at least one filament in each flask being infected with the parasite. These flasks were then placed in the algal culture room.

For the first month or so the host cells seemed to grow slightly or at least to maintain themselves. The parasite continued its growth and development as

before for a period of about two weeks, the zoospores reinfecting the host cells. As the cultures aged, instead of summer prosori, only winter prosori or resting bodies were formed. After about two months, during which time the medium was renewed once, the cultures consisted of dead filaments of host cells with many resting bodies in each cell.

No resting bodies were seen to germinate during the above period. Various methods were used in attempts to germinate the resting bodies. These consisted of alternating periods of light and dark, alternating periods of high and low temperatures, and washing with fresh lake and distilled water. None of these attempts was successful, and there was no evidence that any resting bodies had germinated or were germinating until after about three months had passed. When germination finally did occur, there was no living host material left.

Species of the genus *Micromyces* have been differentiated by the size and structure of prosorus, sorus, resting bodies, size of zoospores and the host. The present species differs from all those previously described in that it is consistently much larger in all phases of its life cycle (see Table I for summary of specific differences).

It has been proposed by Karling (1953) that *Micromyces* be merged with the genus *Synchytrium*. He suggests that differences between the two genera, i.e. amoeboid movements of the thallus of *Micromyces*, differences in size, spininess

TABLE I

A summary of the specific differences compiled from the literature

Species	Prosorus	Spines on Prosorus	Sporangium	Zoospore	Resting Body
M. zygogonii Couch, Canter, Sparrow	Diam. 11–18 μ	14–18; 3.5–7.5 μ long	4–8/sorus; 6–11 x 12 μ	Diam. 2 μ	Diam. 11–15μ
M. spirogyrae Skvortzow	Spherical-ellipsoidal	3.5–3.8 μ long	Not observed	Not observed	22.5–26.0 x 18.0–22.5 μ
M. Petersenii Scherffel	"As in *M. zygogonii*"	"Short, conical."	"As in *M. zygogonii*"	"6 μ long x 2 μ thick"	Not observed
Canter	Diam. 10–15 μ	6–12 (2) μ long	4/sorus: diam. 7 μ	"5.5 μ long x 1.5 μ"	Not observed
M. longispinosus Couch	Diam. 10–33.6 (most 21.0) μ	12–24; up to 22 (most 12) μ long	8–24/sorus; 8.4 x 9.6 μ	Diam. 1 μ	Spined; diam. 16–21 μ
M. laevis Canter	Diam. 7.6–18 μ	Smooth	4–8/sorus	Diam. 1 μ	No spines; diam. 12.7 μ
M. ovalis Rieth	8–14 (most 8) x 6–31 (most 12–18) μ	4–6 rings; "shaped like shark's teeth"	4/sorus	Diam. 1 μ	Larger than prosorus; spines as on prosorus
M. grandis	Diam. 30.4–51.2 (most 40.0–48.0) μ	17–25; 38.4–67.2 (most 51.2–60.6) μ long	33–54/sorus; 9.6–11.2 x 16.0–23.1 μ	Diam. 2.1–2.8 μ	Diam. 16.0–32.0 (most 24.5–27.0) μ. 20–24 spines; 9.6–24.0 μ long

of resting spores, habitats and hosts, are not generically significant, and are "outweighed by the fundamental structural and developmental similarities of the two genera." He further proposes that all fully known members be grouped into six subgenera as indicated in a key which is included in the paper. This "key is an extension and modification of the one proposed by Fitzpatrick (1930), and is based on the presence or absence of summer sporangial sori, prosori and resting spore germination, as well as on the development of the mature vegetative thallus into a sorus or its function as a prosorus." According to Karling (1953) a classification of all the species of *Synchytrium* which have been described up to the present time cannot be made, because many of them are not fully known. "Of the 158 or more species reported in the literature less than 25 are completely known and can be classified with certainty."

Micromycopsis Scherffel, another aquatic member of the Synchytriaceae, differs from *Micromyces* in that the prosorus develops a germ tube through which the protoplasm flows outside the host cell, forming an epibiotic sorus. Canter (1949) and Rieth (1950) report the occurrence of transition stages, with respect to prosoral germination, between *Micromyces* and *Micromycopsis*, and Canter states that in the future "*Micromyces* and *Micromycopsis* may have to be merged into one genus."

It is obvious from the above that much remains to be known about the Synchytriaceae. It is indeed reasonable that with further researches in this group a mergence of *Synchytrium* and *Micromyces* might become necessary and might well be the key, as Karling (1954) suggests, to an evolutionary understanding of these forms. However, in view of the lack of comparative studies of *Synchytrium* and *Micromyces* or, for that matter, a complete cytological study of *Micromyces*, and because of incomplete knowledge of the life histories of the other aquatic forms, it would seem that a merging of these two genera is of uncertain value at this time.

SUMMARY.—A new member of the aquatic Synchytriaceae is described. This new species, an obligate parasite on *Spirogyra sp.*, is named *Micromyces grandis*. It is characterized by extremely large size in all phases of its life cycle, by causing unique hypertrophy of the host cell resulting in peculiar geniculations in the host filament, and by its slowness of development. A description of the development and life history of this new fungus is included, and a tabular comparison is made with other species of the genus *Micromyces*.

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DISTRIBUTION AND SPECIATION OF THE GENUS LUDWIGIA IN NORTH CAROLINA*

BY JAMES ALAN DUKE

Department of Botany, University of North Carolina, Chapel Hill, North Carolina

INTRODUCTION.—Interest in this genus has been stimulated by the very diverse nature of the species and the frequent difficulties encountered in distinguishing them. Determining the species is often made difficult by inconstancies in the key characters such as style length, pedicel length, sepal and petal length, capsule length and breadth, bracteole length and position, leaf size and shape, sepal size and shape, petiolation, pubescence, and seed coloration. In spite of a great diversity in the genus, it appears that the species show varying degrees of intergradation.

The purpose of this study has been to determine the distribution and characterization of the various species found in North Carolina. Many species were described in the late eighteenth and early nineteenth centuries, often simultaneously by different botanists, causing synonymy to be quite prevalent in the genus. Munz (1944) lists synonyms for the species; synonymy does not, however, enter into the scope of this paper.

Extensive field work has been pursued in conjunction with examination of

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over 500 herbarium specimens. All specimens of *Ludwigia* in the herbaria of Duke University (DUKE), North Carolina State College (NCS), and the University of North Carolina (NCU) have been studied. Because of lack of material, specimens of the Section *Ludwigiaria* have been obtained from the United States National Herbarium (US) and specimens of *L. arcuata*, *L. linifolia* and *L. sphaerocarpa* from the Gray Herbarium (GH) and the Herbarium of the New York Botanical Garden (NY).

HISTORICAL NOTES.—In 1753, Linnaeus described three species of *Ludwigia*, of which two are found in North Carolina and one is an old world species. Walter (1788), in treating the flora of Carolina, gave terse descriptions of ten species and he is now considered author of five. Michaux (1803), in his *Flora Boreali-Americans*, included nine species, but is considered author of only two. Pursh (1816) had ten species in his flora. In 1821, Stephen Elliot listed sixteen species, and he is now the accredited author of four. Torrey and Gray (1838) considered sixteen species to occur in the southeastern United States; by 1933, Small had twenty-three species distributed among three genera. Fassett (1940) had eight species in his manual of aquatics and Muenscher (1944) had four. The monograph of Munz (1944) included twenty-five American species. Fernald's manual (1950) treated fourteen species, although Fernald stated that his text is derived from Fernald and Griscom (1935) which only treated four species. Gleason's flora for the northeastern United States (1952) contained twelve species.

In Curtis' catalogue of North Carolina plants (1867) were thirteen species of *Ludwigia*, two of which have since been divided, bringing Curtis' total to fifteen. His list did not contain *L. glandulosa*, which is rather common in the state, but it did contain *L. arcuata* (which in his time included *L. brevipes*). Munz (1944) attributed North Carolina distribution to fifteen species. On olivine deposits, Radford (1948) found *L. palustris*. In their account of the spring and early summer flora of the piedmont, Blomquist and Oosting (1953) mentioned only the two ubiquitous species, *L. palustris* and *L. alternifolia*.

Munz' very thorough monograph (1944) is the most comprehensive treatment of the genus and has been a constant source of reference in this problem.

TREATMENT OF THE GENUS.—This genus, composed of about thirty species, is rather typical of the Onagraceae with its tetramerous flowers and inferior ovary. It differs from other primitive members of the family in the possession of a short capsule and only four stamens per flower. Herbarium records indicate that at least fifteen species occur in North Carolina.

The genus exhibits such a diverse array of characters that its four sections have often been elevated to generic status. Leaves are either alternate or opposite (whorled in one species). Plant habit seems to be correlated with leaf arrangement; the alternate-leaved species are mostly upright and suffruticose, the opposite-leaved members are fleshy and decumbent, often forming extensive clones. Leaves are entire, glabrous to pilose with long unicellular trichomes slightly swollen at the base, sessile or petiolate, linear to broad-obovate. Stigmas vary from capitate to four-lobed and generally have the anthers closely apposed to them. In some species, the summit of the capsule is crowned by a four-lobed stylopodium which remains after the style falls. Deciduous petals occasionally

TABLE I

Illustration of possible parallel evolution among the alternate-leaved and opposite-leaved species. (Measurements given in millimeters)

Species	Style	Petal	Sepal	Capsule	Bracteole	Pedicel
Alternate-leaved species						
L. virgata	6–10	10–15	6–12	4–6	1–6	5–17
L. alternifolia	1.5–4	3–10	3–10	2–6	1–4	1.5–8
L. alata	*Ca.* 1	Absent	1.5–3.5	2–4	2–4	Sessile
L. microcarpa	*Ca.* 1	Absent	1–2	1–1.5	0.5–1.5	Sessile
Opposite-leaved species						
L. arcuata	3–4	6–12	4–7	3–8	1–3	12–35
L. brevipes	1.5–3	3–6	2.5–6	6–11	1.5–4	5–16
L. natans	*Ca.* 1	2–3	2–3	3–10	1.5–5	0–4
L. palustris	0.5–1	Absent	1–2	1.5–5	0–2	Sessile

exceed the sepals; more usually they are shorter or entirely absent. Sepals vary from linear to broad-deltoid and sometimes exceed the capsule. The capsule is subrotund, obpyramidal, obconical, or cylindric; sessile to long-pedicellate; with corners winged or rounded. At the base of the capsule or on the pedicel is typically borne a pair of bracteoles, either minute or quite conspicuous, linear to ovate. Seeds are copiously produced in the four chambers of the capsule and are oval (cylindric in one species); the raphe is often conspicuously lighter or darker than the seed proper.

Often the genus can be recognized at a distance because of a reddish coloration in the stems, leaves, sepals, bracteoles, and ovaries. This coloration, probably due to anthocyanin, is frequently more pronounced in drier, less favorable habitats. Occasionally, in clones near water, parts of the clone farther from the water are redder. Several species, especially *L. microcarpa*, have small red glands at intervals along the leaf margins. These marginal glands, where obvious, are valuable for identifying the genus in a vegetative state.

The genus is divided into four sections, two of which are alternate-leaved, two, opposite-leaved. However, both the alternate- and opposite-leaved sections seem to exhibit similar evolutionary trends. Parallel tendencies are most strongly suggested by the lengths of the styles, petals, sepals, capsules, bracteoles, and pedicels. Table I illustrates the possibility of parallelism in the evolution of alternate- and opposite-leaved species.

KEY TO NORTH CAROLINA SPECIES

Leaves alternate:

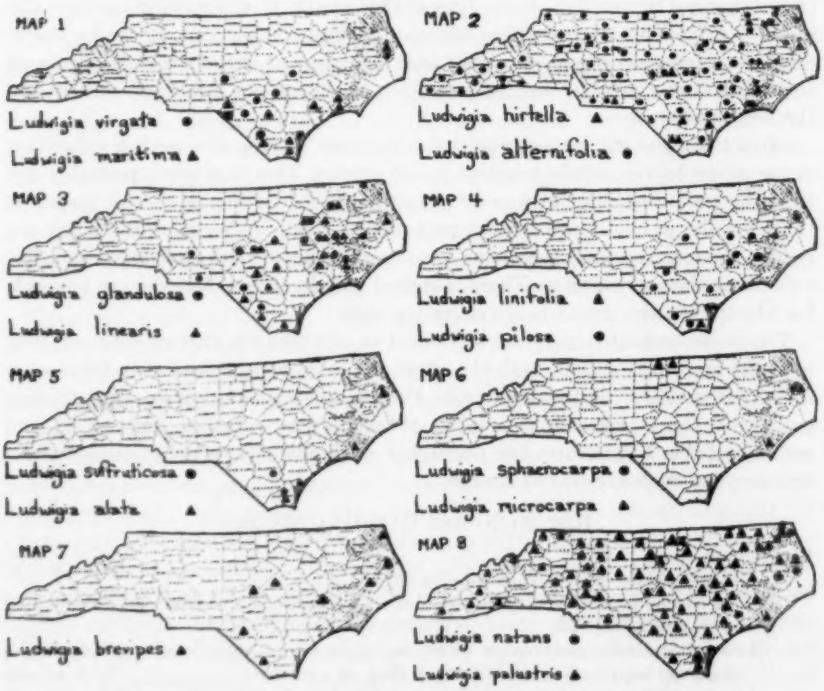
Capsule pedicellate (Section *Ludwigiaria* DC.):

Leaves sessile; stylopodium prominent, dome-shaped, often 4-lobed; pedicel equaling or exceeding capsule:

Lowermost leaves glabrous or nearly so; style over 6 mm. long, much exceeding stamens; sepals at least 1½ × as long as capsule.....1. *L. virgata*

Lowermost leaves pubescent or hirsute; style less than 6 mm., equaling or barely

exceeding stamens:
Sepals ovate, not much exceeding capsule; capsule appressed-pubescent; bracteoles rarely reaching to base of sepals in anthesis.....2. *L. maritima*
Sepals narrow-deltoid, at least 1½ × as long as capsule; capsule erect-hirsute; bracteoles usually reaching to base of sepals in anthesis.....3. *L. hirtella*
Leaves with petioles or attenuate bases; stylopodium low and rounded; pedicels shorter than, or equaling, capsule.....4. *L. alternifolia*
Capsule sessile or subsessile (Section *Microcarpium* Munz):
Capsule at least twice as long as broad:
Leaves lanceolate; sepals mostly less than 2 mm. long; capsule cylindric with bracteoles no longer than 1 mm.; petals absent.....5. *L. glandulosa*
Leaves linear; sepals mostly more than 2.5 mm. long; capsule long-obconical or cylindric with bracteoles more than 1 mm. long; petals present:
Capsule long-obconical; sepals narrow-deltoid; seeds usually light tan
6. *L. linearis*
Capsule cylindric; sepals linear; seeds usually dark brown with a whitish raphe
7. *L. linifolia*
Capsule about as long as broad:
Bracteoles narrow-lanceolate to ovate, at least 2 mm. long:
Entire plant pilose; upper leaves elliptic.....8. *L. pilosa*
Plant glabrous except for stolons and extremities; upper leaves lance-linear:
Flowers in terminal heads; capsule rounded.....9. *L. suffruticosa*
Flowers not in heads; capsule winged.....10. *L. alata*



MAPS 1–8. Distribution of species of *Ludwigia* found in North Carolina.

Bracteoles narrower; less tha 2 mm. long:
Cauline leaves linear to narrow-ovate; capsule rotund, over 2 mm. long
11. *L. sphaerocarpa*
Cauline leaves obovate to spatulate with conspicuous marginal glands; capsule obpyramidal, less than 2 mm. long.....12. *L. microcarpa*
Leaves opposite:
Capsule pedicellate (Section *Ludwigiantha* Torrey and Gray):
Petals exceeding sepals; capsules 3–7 mm. long, no longer than sepals; pedicels 15–35 mm. long, exceeding leaves.....13. *L. arcuata*
Petals equaling sepals; capsules (4) 6–11 mm. long, longer than sepals; pedicels 5–16 mm. long, usually not exceeding leaves.....14. *L. brevipes*
Capsule sessile, rarely on pedicels up to 6 mm. long (Section *Dantia* DC.):
Petals present; capsule long-obconical, usually at least twice as long as broad, without longitudinal green stripes; bracteoles 1.5–5 mm. long, usually borne above base of capsule; sepals at least 2 mm. long.....15. *L. natans*
Petals lacking; capsule broad-obpyramidal, rarely twice as long as broad, with green stripes extending from the base nearly to the sinuses of the calyx; bracteoles usually less than 1 mm. long, basal; sepals usually less than 2 mm. long....16. *L. palustris*

1. *Ludwigia virgata* Michx. Pl. Bor. Am. **1**: 89. 1803

Found in sandy savannas, pocosins, pinelands and roadsides, this species is probably restricted to the coastal plain, although extending farther inland than the closely related *L. maritima*. (Map 1).

Munz (1944) states as a key character: "Flowers in axils of bracts less than 1 cm. long". In over half the specimens examined in this study, some of the bracts were over 1 cm. long; in one form (NCU, *Godfrey 10016*), bracts were up to 3 cm. long.

2. *Ludwigia maritima* Harper. Torreya **4**: 163. 1904

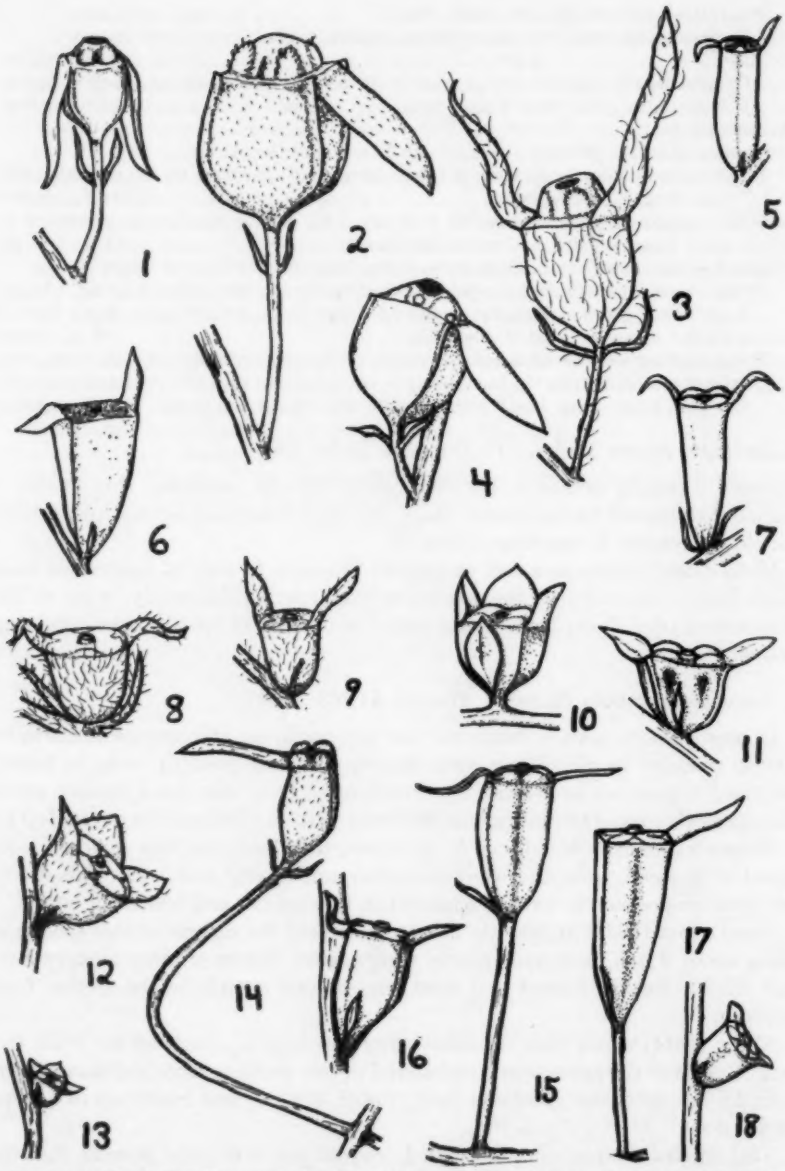
In sandy places, usually damp but not necessarily so, this species seems to be mostly confined to coastal counties. Although it may possibly occur in southeastern Virginia, no herbarium specimens have been seen from farther north than Dare County. The most inland collection is from Scotland County. (Map 1).

Harper (1904), in describing *L. maritima*, mentions that the sepals are reflexed at anthesis, soon afterward ascending, and finally deciduous. This down-the-stem progression is usually apparent in this species and absent in others.

Small's text (1933) apparently errs in describing the capsule of this species as being about 2 mm. long and slightly wing-angled. Works of other authors indicate that it has the largest and most wing-angled capsule in the section *Ludwigiaria*.

Munz (1944) states that the subtending leaves of *L. maritima* are 1–2.5 cm. long. Over half the specimens encountered in this problem have had some bracts over 2.5 cm. long; one specimen (NCU, *Coker, 9/2/46*) had bracts up to 8.5 cm. long.

This species is often confused with *L. virgata* and it is quite possible that the two hybridize, although no proof is available. Hybridization is suggested by the fact that when one character is intermediate, other differentiating characters also tend to be intermediate (NCS, *Godfrey 48375*). The style of *L. virgata* is much longer than the stamens; in other related species, the styles and stamens are



FIGS. 1–4. North Carolina representatives of Section *Ludwigiaria*. ×6. FIG. 1. *L. virgata*. FIG. 2. *L. maritima*. FIG. 3. *L. hirtella*. FIG. 4. *L. alternifolia*. FIGS. 5–13. North Carolina representatives of Section *Microcarpium*. ×6. FIG. 5. *L. glandulosa*. FIG. 6. *L. linearis*. FIG. 7. *L. linifolia*. FIG. 8. *L. pilosa*. FIG. 9. Possible hybrid between *L. glandulosa* and *L.*

much the same size; so that, even before the sepals have unfolded in flowering, the stigma is frequently already covered with pollen, suggesting that self-pollination prevails in these species. *L. virgata* with its exerted style may then be more subject to cross-pollination. *L. maritima* appears to be its closest relative on basis of leaf, pedicel, and capsule characters. The two species are frequently confused. The characteristics of a typical *L. maritima* which differentiate it from a typical *L. virgata* are: (1) a larger, more rotund capsule; (2) a shorter style, hardly exceeding the stamens; (3) more ovate sepals which barely exceed the mature capsule and which are less than 3 times as long as the hypanthium at anthesis; (4) an evident pubescence, especially of the lower leaves. When a plant is found to be questionable in one of these characteristics, it frequently is questionable in all of them. Subsequent work will possibly demonstrate that these questionable forms are hybrids.

3. *Ludwigia hirtella* Raf. Med. Rep. N. Y. **5**: 358. 1808

Found in damp, dry, or burned-over sandy places, this species is typically found on the coastal plain but extends farther inland than the preceding two species. (Map 2).

This rather distinct species may occasionally be confused with pubescent forms of *L. alternifolia* but may be distinguished by its sessile leaves, longer bracteoles, more prominent stylopodium and narrower sepals. Except for pubescence, *L. hirtella* is also sometimes suggestive of *L. virgata*; one specimen (US, *McDougall 1692*), which was exceptional in its long styles (up to 7 mm.), was very similar to *L. virgata*.

4. *Ludwigia alternifolia* L. Sp. Pl. 118. 1753

Common in sunny swamps, beside creeks, in dry or wet roadside ditches, and occasionally in meadows and waste places, this species is ubiquitous and may be expected throughout the state. (Map 2).

Specimens vary in the amount of pubescence. Palmer and Steyermark (1938) describe a pubescent midwestern variety, *L. alternifolia* L. var. *pubescens* Palmer and Steyermark, which differs from the typical variety by having the stems, leaves, pedicels, and capsules densely pubescent with spreading hairs. Munz (1944) says the pubescence is erect. Pubescence in the North Carolina specimens (e.g. NCU, *Totten & Smith, Aug. 1944*) is appressed and scanty, and our pubescent forms are best considered *L. alternifolia* L. var. *typica* Munz.

5. *Ludwigia glandulosa* Walt. Fl. Car. 88. 1788

Found frequently in mud beside creeks and occasionally in roadside ditches where it may be dominant, this species probably has a wider distribution in North Carolina than any other member of the section *Microcarpium*. Field work in this study indicates that this species may be expected in the coastal plain and

pilosa. FIG. 10. *L. suffruticosa*. FIG. 11. *L. alata*. FIG. 12. *L. sphaerocarpa*. FIG. 13. *L. microcarpa*. FIGS. 14–18. Representatives of Sections *Ludwigiantha* and *Isnardia*. ×6. FIG. 14. *L. arcuata*. FIG. 15. *L. brevipes*. FIG. 16. *L. natans*. FIG. 17. Form intermediate between *L. brevipes* and *L. natans*. FIG. 18. *L. palustris*.

lower piedmont. Herbarium material prior to this study consisted of very few specimens, all from the coastal plain; this scarcity was probably due to the inconspicuous nature of this plant. (Map 3).

Munz (1944) cites specimens from Florida, Texas, and Louisiana of a pubescent variety, *L. glandulosa* Walt. var. *Torreyi* Munz which differs from the typical variety in having the hypanthium and sepals minutely strigulose, the sepals 1–1.5 mm. long, and the capsule 2–4 mm. long. He describes the typical variety as having glabrous sepals and hypanthia, sepals 1.8–2 mm. long, and capsules 6–8 mm. long. Many North Carolina plants (NCU, *Duke 5191, 5071, & 5467*) have capsules varying from 4–6 mm; sepal and pubescence characters however would indicate that these are *L. glandulosa* Walt var. *typica* Munz. A peculiar pubescent form, presumed to represent a hybrid between *L. glandulosa* and *L. pilosa*, will be discussed under *L. pilosa*.

6. *Ludwigia linearis* Walt. Fl. Car. 89. 1788

Found in sandy roadside ditches, savannas, and beside water, usually in a sunny situation, this species is probably limited to the coastal plain. (Map 3).

All material from North Carolina seems to be *L. linearis* Walt. var. *typica* Munz. A densely puberulent variety, *L. linearis* Walt. var. *puberula* Engelm. & Gray, is described as occurring in the Gulf States. None of the North Carolina material has been puberulent.

7. *Ludwigia linifolia* Poir. *in* Lam. Encycl., Suppl. **5**: 513. 1813

Found in pinelands and sandy ditches, this species appears to be uncommon in North Carolina. Herbarium specimens represent only two counties, New Hanover and Brunswick. *L. linifolia* probably has a distribution similar to that of *L. suffructicosa* and *L. alata*. (Map 4).

Usually the seeds of *L. linifolia* are dark brown-maroon with a whitish raphe and contrast with the light tan seeds of *L. linearis* which have no striking raphe differentiation. As in other species, the seed coloration seems to be somewhat variable.

8. *Ludwigia pilosa* Walt. Fl. Car. 89. 1788

Found mostly in the coastal plain, frequently in roadside ditches, occasionally

TABLE II

Comparison of characteristics of possible hybrid with both parents.
(Measurements given in millimeters)

	L. pilosa (NCU, *Duke 54284*)	?? Hybrid ?? (NCU, *Duke 54276*)	*L. glandulosa* (NCU, *Duke 54279*)
Capsule length	3–4	3–5	4–7
Capsule width	3–4	2.5–3	1.5–2
Sepal length	3–4	2–3	1–2
Sepal width	2–3	1.5–2	1–1.5
Bracteole length	3–5	1–1.5	Less than 1
Pilosity	Pilose	Intermediate	Glabrous

beside streams, this species often forms extensive stands much to the exclusion of other plants. (Map 4).

With its rounded pilose capsule and very long bracteoles, this constitutes a very distinct species. In all specimens studied except one (NCU, *Duke 54226*), bracteoles exceed the capsule.

A peculiar colony consisting of *L. pilosa*, *L. glandulosa*, and a form that appeared intermediate between them was found in Hyde County, 1.2 miles north of Scranton Creek on Highway 264. On both sides of the road were ditches with standing water; on the east side both species were found, sometimes touching each other, with *L. glandulosa* more abundant; on the west side both species were found, but *L. pilosa* was more abundant, and the form which appeared intermediate between the two species was also rather abundant. Whether or not this is a hybrid cannot be stated with certainty, but superficially it appears to be. Figure 9 and Table II serve to illustrate this.

Because of the frequent apposition of the anthers to the style of the opening flower, *Ludwigia* appears to be self-pollinating. How hybridization might have occurred can only be conjectured. Since flowers of both species are apetalous and inconspicuous, insect visitors are probably phyllophagous. An insect might eat leaves and sepals of both species indiscriminately and in so doing transfer pollen, in rare instances bringing about cross-pollination. Although no insects have been seen directly on the flowers in the field, some *Ludwigia* and *Jussiaea* have almost been stripped of their leaves by caterpillars, and such caterpillars might accidentally have come in contact with flowers. It is here suggested that self-pollination is the rule in this genus, and that cross-pollination is a very rare exception to the rule.

9. *Ludwigia suffruticosa* Walt. Fl. Car. 90. 1788

Found in peaty ponds, marshes and salt meadows, this species is probably confined to coastal counties. Herbarium specimens are from Bladen, Brunswick, and New Hanover Counties. North Carolina is perhaps the northern limit of *L. suffruticosa*. (Map 5).

The subcapitate inflorescence and virgate habit of this species make it quite distinct. The inflorescence of *L. pilosa* sometimes approaches a capitate condition (NCU, *Smith 44*) but is never so compact as in *L. suffructicosa*.

10. *Ludwigia alata* Ell. Sketch Bot. S. C. & Ga. 1: 212. 1821

Collections indicate that this species grows in marshes, sometimes brackish, near the coast. Herbarium specimens are from Dare, Carteret, and Brunswick Counties. (Map 5).

Small (1933) lists a closely related species, *L. lanceolata* Ell., as occurring in North Carolina but Munz (1944) limits it northerly to Georgia. So far, this species has not been encountered in the field or the herbaria from North Carolina, so the distribution given by Munz is considered to be correct.

11. *Ludwigia sphaerocarpa* Ell. Sketch Bot. S. Car. & Ga. 1: 213. 1821

Only three collections have been seen from North Carolina (NCU, *Radford & Stewart 895; Duke 54268, 54269*) and all these were from an acid bog with *Sphag-*

num, *Taxodium* and *Smilax* in Dare County. Other species of *Ludwigia* are rare in such a habitat; whether it is typical for this species is not certain. (Map 1).

Fernald and Griscom (1935) describe four varieties of *L. sphaerocarpa*, one listed as occurring in North Carolina, the others being more northern. They key the varieties very much as follows:

Rameal leaves strongly reduced, glabrous or pubescent, lanceolate:
Mature hypanthium small, 2.5–3.2 mm. long by 2.8–4 mm. broad, averaging broader than long:
Only hypanthium pubescent; glabrous leaves narrowly linear-lanceolate and attenuate.....var. *typica*
Hypanthium, branches and leaves pubescent; leaves more broadly lanceolate, not attenuate.....var. *jungens*
Mature hypanthium larger, 3.5–4.6 mm. long, 3.2–4 mm. broad, averaging longer than broad.....var. *macrocarpa*
Rameal leaves scarcely smaller than the primary ones, pubescent, narrowly oblong; stems pubescent; hypanthium pubescent, 3 mm. long, about as wide.....var. *Deamii*

Munz (1944), who rejects var. *Deamii* as based on inadequate material, would key the varieties as follows:

Fruit crowded on branches, 3.5–4.5 mm. long, not so wide.....var. *macrocarpa*
Fruit not crowded on braches, 2.5–3.2 mm. long, usually wider:
Main stems and leaves usually glabrous; main leaves linear-lanceolate and more than 7 cm. long.....var. *typica*
Main stems and leaves pubescent to strigose, lanceolate, usually less than 7 cm. long var. *jungens*

Munz (1944) and Fernald and Griscom (1935) cite no material from North Carolina, but consider only *L. sphaerocarpa* var. *typica* to occur here. The North Carolina material has had fruits 2–2.5 mm. long, usually wider; pubescence of fruits, leaves and branches; narrow-lanceolate leaves of which none were over 4 mm. long. According to the preceding keys, the North Carolina material seen best fits *Ludwigia sphaerocarpa* Ell. var *jungens* Fern. & Griscom, a variety hitherto not recorded from this state.

12. *Ludwigia microcarpa* Michx. Fl. Bor. Am. **1**: 88. 1803

A peculiar disjunction exists in the distribution of this species as represented by herbarium specimens. Of these, all but two are from marshes, flats and roadside ditches in Dare and Carteret Counties. Batson (1952) mentions finding this species in three localities in his study of the middle piedmont. Specimens observed from Granville and Person Counties (DUKE, *Batson 1074*, *1075*) are typical of *L. microcarpa*. Perhaps this species is fairly widespread but easily overlooked. (Map 6).

In all North Carolina specimens observed the seeds had a dark maroon-brown coloration with no conspicuous raphe differentiation. Among the Florida specimens examined, however, some had maroon and others had light tan seeds. These light tan seeds resemble those of the preceding three species except in lacking the raphe differentiation believed to be typical of them.

The leaves of this species are very conspicuously marked with marginal glands, much more outstanding than in any other species.

13. *Ludwigia arcuata* Walt. Fl. Car. 89. 1788

Although several authors (Fassett, 1940; Small, 1933) give the distribution of *L. arcuata* as from Florida to Virginia, it seems probable, as suggested by Munz (1944) and Gleason (1952) that this species does not occur north of South Carolina. No specimens positively identifiable as *L. arcuata* have been encountered in North Carolina in this study.

No authentic specimens have been seen from North Carolina. Specimens which have some characters heretofore attributed to *L. arcuata* are treated under the discussion of *L. brevipes*.

In all specimens except one (GH, *Torrey*, Fla. 1839), which was peculiar in having the capsule 9 mm. long, the sepals have been as long as the capsule. In *L. brevipes*, however, the sepals are usually shorter than the capsule.

14. *Ludwigia brevipes* (Long) E. H. Eames. Rhodora **35**: 228. 1933

Found in sandy marshes, bogs, and streamsides, this species probably occurs in all the coastal plain counties. Most collections are from habitats inundated in wet seasons and exposed in dry seasons. Farthest inland stations are in Harnett and Johnston Counties (NCS, *Whitford 256;* NCU, *Duke 54148*). (Map 7).

Section *Ludwigiantha* is still in need of research. All specimens from Robeson County (NCS, *Fox 5573;* NCU, *Duke 54159, 54161*) have proved difficult. The plant formed large mats, 2–4 inches deep and several yards in diameter. It was atypical of *L. brevipes* in that the pedicels exceeded the subtending leaves and the capsule only barely exceeded the sepals. Leaves were much smaller than is typical of *L. brevipes*, typically being less than 2 mm. wide and shorter than the pedicels. Raphes of this plant were darker than the seeds, a characteristic believed typical of *L. brevipes*. All specimens of *L. brevipes* studied have had darker raphes; all *L. arcuata*, lighter raphes.

15. *Ludwigia natans* Ell. Sketch Bot. S. C. & Ga. 1: 551. 1821

Found in marshes, bogs, roadside ditches and along creeks, in either sandy or muddy habitats, this species seems to be restricted to the lower portion of the coastal plain. (Map 8).

Elliot (1821), in the original description of *L. natans*, makes no mention of the bracteoles, although they are generally more obvious than in *L. palustris*; to *L. palustris* he attributes "small subulate leaves at the base of each flower."

Gleason (1952), contrary to most authors, considers both *L. natans* and *L. palustris* to be apetalous. Petals are present in *L. natans* but are small and quite deciduous. He also states that *L. natans* has smaller leaves than *L. palustris*, a condition generally not true in the North Carolina material.

Fernald and Griscom (1935) describe three varieties of this species, two of which are supposed to occur on the eastern coast. They key the varieties as follows:

Mature fruit (excluding calyx-lobes) 4–5.6 (6) mm. long.....*L. natans* var. *typica*
Mature fruit 6–10 mm. long, usually more tapering at base.
  Fruit sessile or subsessile.....var. *rotundata*
  Fruit on distinct pedicels up to 4 mm. long.....var. *stipitata*

Munz, in his monograph of 1944, presents a more comprehensive key:

Fruits 3–5 (6) mm. long, sessile or on pedicels up to 1 mm. long; bracteoles mostly 1–3 mm. long; petioles mostly 3–10 mm. long.....var. *typica*
Fruits 6–8 mm. long; bracteoles 2–5 mm. long; petioles 5–20 mm. long.
Fruits sessile, mostly 2–2.5 mm. thick.....var. *rotundata*
Fruit on pedicels 2–4 mm. long and mostly 3–3.5 mm. thick.....var. *stipitata*

It has been very difficult to determine the variety of some collections. In several, the pedicels have been over 1 mm. long (NCU, *Ted & Bess Browne 616; Radford 6658*). Occasionally a plant will have capsules varying from 3 to 7 mm. in length, with the smaller fruits being mostly on branches; often accompanying this variation is a proportionate variation in bracteole length. (NCU, *Duke 542*).

Most North Carolina specimens are believed to be *L. natans* Ell. var. *typica* Fern. & Griscom, although they exhibit a greater variability than is expressed in the keys of Fernald and Griscom (1935) and Munz (1944). One atypical specimen (NCU, *Radford 5816*) had subrotund capsules, 2–3 mm. long, 2.5 mm. wide; with bracteoles unusually short, some basal, some almost at the base of the calyx.

Growing submerged with *L. palustris* in a Dare County marsh was a peculiar specimen (NCU, *Duke 54243*) with vegetative characters very suggestive of *L. natans* but with reproductive characters of *L. brevipes*. The plant seemed to be intermediate between the two (as does *L. natans* Ell. var. *stipitata* Fern. & Griscom). Leaves were narrow-ovate, 10–35 mm. long, 6–12 mm. wide, and sessile or on petioles up to 7 mm. long. No leaves of this type are reported for *L. brevipes*. Fruits were 6–8 mm. long, 2–2.5 mm. wide, on pedicels 3–6 mm. long, with basal bracteoles 3–4 mm. long and sepals 3–4 mm. long. Thus the fruits are more like those of *L. brevipes* than of any of the eastern varieties of *L. natans*. If this plant is *L. brevipes*, it is highly atypical; if it is *L. natans*, it cannot be resolved to any of the three varieties with satisfaction but best fits *L. natans* Ell. var. *stipitata* Fern. & Griscom, a variety hitherto reported only from the West Coast. It is illustrated in fig. 17.

Fernald and Griscom (1935) list var. *rotundata* as occurring in "Mexico, the Greater Antilles, Bermuda and from Georgia and Florida to Texas". Munz (1944) gives its distribution as "Atlantic Coast of U. S. to Rocky Mts. and West Indies". One specimen (NCU, *Ashe, 1898*) from Dare County clearly fits *Ludwigia natans* Ell. var. *rotundata* (Criseb.) Fern. & Griscom, with its fruit 6–10 mm. long, 2.5 mm. wide, bracteoles 3–5 mm. long and petioles 7–9 mm. long.

16. *Ludwigia palustris* (L) Ell. Sketch Bot. S. C. & Ga. 1: 211. 1821.

This ubiquitous species may be expected throughout North Carolina in a variety of habitats. Field observations suggest that this plant requires water for its establishment but can withstand desiccation once established. Rarity of the plant near small mountain streams may perhaps be due to lack of alluvium. (Map 8).

Fernald and Griscom (1935), who describe 4 varieties of *L. palustris*, would key the 2 varieties found in North Carolina as follows:

Mature hypanthium 2 (rarely 1.8)—3.5 mm. in diameter at the middle; calyx lobes broadly deltoid and scarcely acuminate; leaf blades of terrestrial state long-petioled, subacute to short-pointed.....var. *americana*
Mature hypanthium 1.4–2 mm. in diameter at the middle; calyx lobes narrowly deltoid to broadly lanceolate, acuminate; leaves long-petioled.....var. *nana*

Fernald and Griscom give the range of var. *nana* as: "Southern Georgia and Florida along the Gulf to Texas; also Cuba, Haiti, southeastern Mexico and Colombia". Fernald (1950) gives Delaware as the northern limit of var. *nana*. Munz (1944), who gives the range of var. *nana* as "southern U. S. to Colombia", would key the North Carolina varieties as follows:

Leaf-blades usually at least half as wide as long; capsules 2–3.5 mm. thick....var. *americana*
Leaf blades one-third to one-fourth as wide as long, mostly less than 1 cm. long; capsules less than 2 mm. thick.....var. *nana*

Distinguishing varieties of the North Carolina material has been difficult and frequently borderline specimens have been encountered. For example, mature capsules in several specimens (NCU, *Fernald & Fogg 570; Radford 4801; Duke 5427, 5430, 5435, 5476, 54201, 54202, 54214, 54219, & 54221*) vary from 1.5–2.5 mm. in maximum thickness. Often associated with this capsule variation is an equally confusing variation in leaf size and shape (NCU, *Radford* in 1946, Madison Co.; *Smith 2000; Duke 5430, 5435, 54118, 54167, & 54214*). Fernald & Fogg's specimen (NCU, *570*) will serve to illustrate the difficulty; maximum fruit widths vary from 1.5–3 mm.; leaves are lanceolate, 7–14 mm. long, 3–5 mm. wide, on very short petioles; sepals are deltoid and acute. Using Munz' key, one would be inclined to call it var. *nana*; with Fernald & Griscom's key, var. *americana*; Fernald and Fogg call it *Ludwigia palustris* (L.) Ell. var. *americana* (DC.) Fernald and Griscom.

Although these varieties are sometimes distinct, certain observations suggest that variation may possibly be due to growth factors: (1) In desiccated places, the main axis of a plant may have large ovate leaves and thick fruits, while branches may have much shorter, narrower leaves and thinner fruits. This suggests that, when becoming established, the plant was subjected to more favorable water and/or other conditions, perhaps resulting in larger capsules and leaves. In some specimens (NCU, *Duke 54214*) branches were more like those of var. *nana* while the main axes were like those of var. *americana*. (2) Larger leaves and fruits are frequently found nearer water, plants farther removed having smaller fruits and leaves. (3) Plants in desiccated places generally tend to be smaller; under these conditions a slight inrolling of the margin causes the leaf to appear narrower. (4) There tends to be a correlation between small leaves and small fruits, so that Munz' key characters seem to remain physically linked.

SUMMARY.—The important systematic works from the time of Linnaeus to the present are briefly mentioned; and a key embracing some new and some old distinctions is provided for the North Carolina species, each of which is discussed separately. A possible parallel evolution exhibited by the alternate- and opposite-leaved species is pointed out.

It is shown that *L. virgata* and *L. maritima* seem to intergrade. A form intermediate between *L. glandulosa* and *L. pilosa*, probably a hybrid, is described. Specimens believed to be *L. sphaerocarpa* var. *jungens*, not previously reported from this state, are cited. Specimens believed intermediate between *L. arcuata*, not yet verified from this state, and *L. brevipes*, have been encountered. A plant intermediate in character between *L. brevipes* and *L. natans* is shown to be closely comparable to *L. natans* var. *stipitata*, a variety supposedly located on the West Coast. Varieties of *L. natans* and *L. palustris* are not clearly defined and seem to intergrade.

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ACTINOSPORANGIACEAE SHOULD BE ACTINOPLANACEAE

BY JOHN N. COUCH

Department of Botany, University of North Carolina, Chapel Hill, North Carolina

Soon after my paper, *A new genus and family of the Actinomycetales, with a revision of the genus Actinoplanes*, appeared in this Journal (1955, **71:** 148–155), Dr. Robert S. Breed called my attention to the fact that the name Actinosporangiaceae was not in accord with either the Botanical Code of Nomenclature or the rules followed in Bacteriology by which a family name must be formed from the name of the type genus. Since the type genus is *Actinoplanes* I propose that the family name be changed to Actinoplanaceae.

In the paper referred to above, p. 154, line 5, "acid-fast" should read "not acid-fast."

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CONTENTS OF VOLUME 71

SEASONAL HISTORY STUDIES ON THE SOUTHERN CORN ROOTWORM AND ITS RELATION TO PEANUT CULTURE IN NORTH CAROLINA. *W. H. Long and J. R. Dogger* 1

ANISOPTERAN ODONATA ON THE SAVANNAH RIVER PLANT, SOUTH CAROLINA. *William H. Cross* 9

DISTRIBUTIONAL RECORDS FOR SOME SCARCE PHALANGIDS IN THE SOUTHERN APPALACHIANS. *Richard L. Hoffman* 17

THE AMPHIBIANS OF NEW HANOVER COUNTY, NORTH CAROLINA. *John B. Funderburg, Jr.* 19

THE STATUS OF THE TURTLE KINOSTERNON BAURI PALMARUM STEJNEGER WITH NOTES ON VARIATION IN THE SPECIES. *Thomas M. Uzzell, Jr., and Albert Schwartz* 28

THE GENUS XYRIS L. IN NORTH CAROLINA. *H. L. Blomquist* 35

ACINETOSPORA BORN. NEW TO NORTH AMERICA. *H. L. Blomquist* 46

NUCLEAR ABERRATIONS IN THE SYNCYTIAL ENDOSPERM OF COCOS NUCIFERA. *Victor M. Cutter, Jr. and Bessie Freeman* 49

A SPECIES OF OLPIDIOPSIS PARASITIC IN ACHLYA GLOMERATA. *T. W. Johnson, Jr.* 58

AN EMBRYOLOGICAL STUDY OF FOUR SPECIES OF ASARUM. *Raymond L. Wyatt* 64

MORPHOLOGICAL STUDIES IN RHAMNACEAE. *Elmer C. Prichard* 82

NORTH AMERICAN LEJEUNEACEAE. I. INTRODUCTION; KEYS TO SUBFAMILIES AND GENERA. *Rudolf M. Schuster* 106

NORTH AMERICAN LEJEUNEACEAE. II. PARADOXAE: THE GENERA APHANOLEJEUNEA AND LEPTOCOLEA. *Rudolf M. Schuster* 126

A NEW GENUS AND FAMILY OF THE ACTINOMYCETALES, WITH A REVISION OF THE GENUS ACTINOPLANES. *John N. Couch* 148

PROCEEDINGS OF THE FIFTY-SECOND ANNUAL MEETING OF THE NORTH CAROLINA ACADEMY OF SCIENCE 157

PROCEEDINGS OF THE ELISHA MITCHELL SCIENTIFIC SOCIETY 180

PROOF OF THE SUM AND DIFFERENCE FORMULAS IN TRIGONOMETRY. *T. F. Hickerson* 181

CONTINUOUS PRODUCTS IN LINEAR SPACES. *J. S. Mac Nerney* 185

A SURVEY OF NORTH CAROLINA SHRIMP NURSERY GROUNDS. *Austin B. Williams* 200

LOCAL VARIATION AND RELATIONSHIPS OF THE CYPRINODONT FISH, FUNDULUS RATHBUNI JORDAN AND MEEK. *Jerram L. Brown* 207

ANOTHER MYCOTYPHA. *Frederick A. Wolf* 213

NORTH AMERICAN LEJEUNEACEAE. III. PARADOXAE: COLOLEJEUNEA, SECTIO MINUTISSIMAE. *Rudolf M. Schuster* 218

MICROMYCES GRANDIS, A NEW MEMBER OF THE AQUATIC SYNCHYTRIACEAE. *Charles E. Miller* 247

DISTRIBUTION AND SPECIATION OF THE GENUS LUDWIGIA IN NORTH CAROLINA. *James Alan Duke* 255

ACTINOSPORANGIACEAE SHOULD BE ACTINOPLANACEAE. *John N. Couch* 269

Vol. 70, no. 2, including pages 105 to 326, was issued on March 10, 1955.
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